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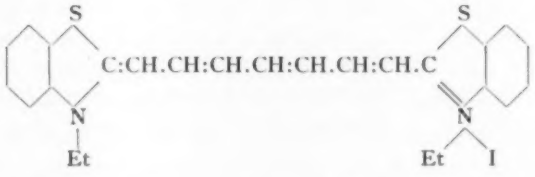
Vol. 219 **MARCH, 1935** **No. 3**

NEW SENSITIZERS FOR THE PHOTOGRAPHY OF THE INFRA-RED. TETRA- AND PENTACARBOCYANINES.*

BY

L. G. S. BROOKER and G. H. KEYES.

It has been shown [1] that considerable improvement in the photography of the infra-red had resulted from the use of sensitizing dyes of the tricarbocyanine series. It was found, for instance that 2,2′-diethylthiatricarbocyanine iodide (I) was considerably

I 

superior to kryptocyanine as a sensitizer for ordinary infra-red photography, especially for objects at a great distance, whilst the dibenzothiatricarbocyanines and the 4,4′-tricarbocyanines (xenocyanine) were also found to be of great value.

In the tricarbocyanines the two heterocyclic nuclei are

*Communication 543 from the Kodak Research Laboratories.

[1] Fisher and Hamer, *J. Chem. Soc.*, 189 (1933), Brooker, Hamer and Mees, *J. Opt. Soc. Amer.*, **23**, 216 (1933).

(Note—The Franklin Institute is not responsible for the statements and opinions advanced by contributors to the JOURNAL.)

linked together by the 7-carbon chain :CH.CH:CH.CH:CH.-CH:CH., and it would be expected that further lengthening of this chain would give rise to cyanine dyes whose absorption bands, and hence their sensitizing bands, are situated still further out in the infra-red.

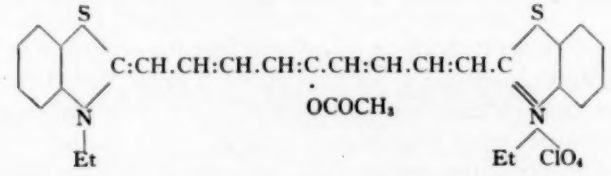
This expectation has been fully realized. We have now prepared cyanine dyes in which the two heterocyclic nuclei are linked together by the 9-carbon chain :CH.CH:CH.CH:-C(O Acyl).CH:CH.CH:CH., and by the 11-carbon chain :CH.CH:CH.CH:C(O Acyl).CH:CH.CH:CH.CH:CH., the dyes containing these chains being named tetracarbocyanines and pentacarbocyanines, respectively.

It should be mentioned that Eggert [2] has referred to the use of tetracarbocyanines (called by him "nonacarbocyanines") as photographic sensitizers for the infra-red.

The chemistry involved in the preparation of the new dyes will be discussed elsewhere, but it may be said that the methods employed are very similar to those used for preparing the tricarbocyanines. In the preferred method of synthesis of the latter, glutaconic aldehyde dianilide hydrochloride (II) was condensed with a suitable quaternary

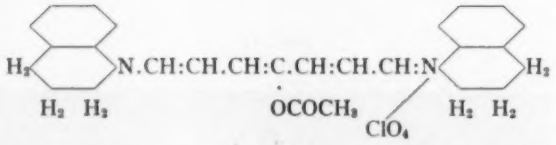
II $C_6H_5.NH.CH:CH.CH:CH.CH:NC_6H_5,HCl$

salt, the 5-carbon chain in II becoming the nucleus of the 7-carbon chain of the resulting tricarbocyanine dye.[3] In the preparation of the new tetracarbocyanines, such as 11-acetoxy-2,2′-diethylthiatetracarbocyanine perchlorate (III), the intermediate 4-acetoxy-$\Delta^{3,5}$-heptadiene-1,7-dial di-tetra-

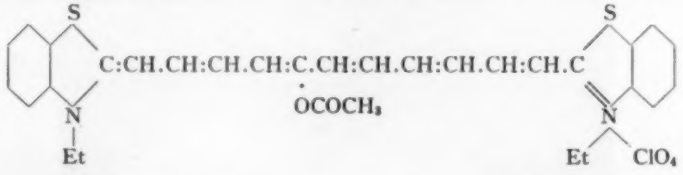
III 

hydroquinolide perchlorate (IV)[4] is condensed with 1-methyl-

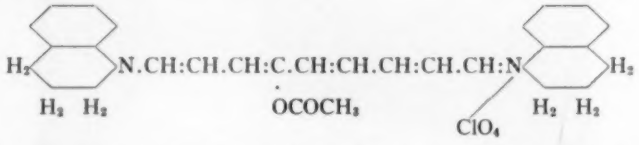
[2] Eggert, *Chemiker-Zeitung*, **58**, 398 (1934).
[3] Fisher and Hamer, *J. Chem. Soc.*, 1933, 189. Cf. Kodak Ltd., B.P. 408,571.
[4] König, *Ber.*, **67**, 1274 (1934).

IV 

benzothiazole etho-p-toluenesulfonate, whilst in the preparation of 11-acetoxy-2,2′-diethylthiapentacarbocyanine perchlorate (V) the same quaternary salt is condensed with

V 

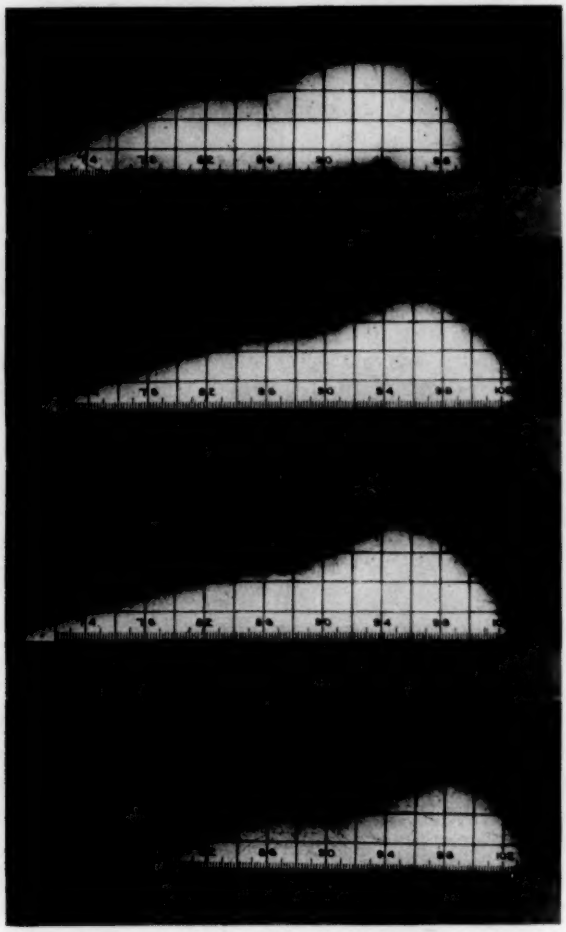
4-acetoxy-$\Delta^{3,5,7}$-nonatriene-1,9-dial di-tetrahydroquinolide perchlorate (VI)[4].

VI 

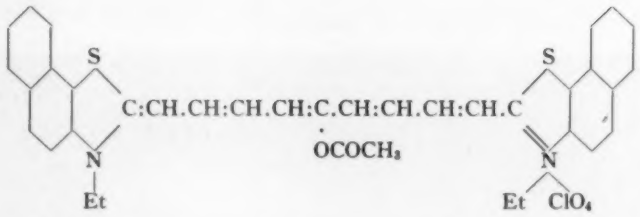
The condensations may be effected in alcoholic solution under the influence of piperidine, or else the components may be allowed to react together in pyridine solution. A third method employs acetic anhydride as medium and fused sodium acetate as condensing agent. In each individual case that method must be determined which gives the best results. Usually the condensations are effected at room temperature or else in the vicinity of the freezing point.

The new polycarbocyanines are, in general, excellent sensitizers. In the tetracarbocyanine series, 11-acetoxy-2,2′-diethylthiatetracarbocyanine perchlorate (III) has a strong maximum at 9400 A. (Fig. 1, *A*), the range 7600 A. to 10,000 A. being especially well covered by the dye. The corresponding thiatetracarbocyanines derived from the methyl-α- and β-naphthothiazoles have also been made. 11-acetoxy-2,2′-diethyl-5,6,5′,6′-dibenzothiatetracarbocyanine perchlorate (VII) confers strong maximum sensitiveness at about 9600 A.

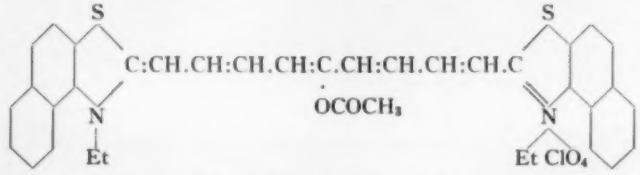
FIG. 1.



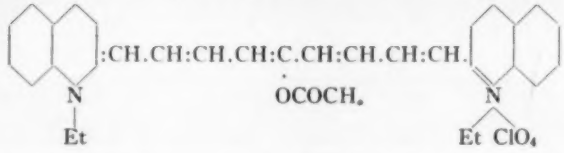
A spectrogram of III: 11-acetoxy-2,2′-diethylthiatetracarbocyanine perchlorate
B spectrogram of VII: 11-acetoxy-2,2′-diethyl-5,6,5′,6′-dibenzothiatetracarbocyanine perchlorate
C spectrogram of VIII: 11-acetoxy-2,2′-diethyl-3,4,3′, 4′-dibenzothiatetracarbocyanine perchlorate
D spectrogram of IX: 13-acetoxy-1,1′-diethyl-2,2′-tetracarbocyanine perchlorate

VII 

(Fig. 1, *B*), the isomeric 11-acetoxy-2,2′-diethyl-3,4,3′,4′-dibenzothiatetracarbocyanine perchlorate (VIII) having very

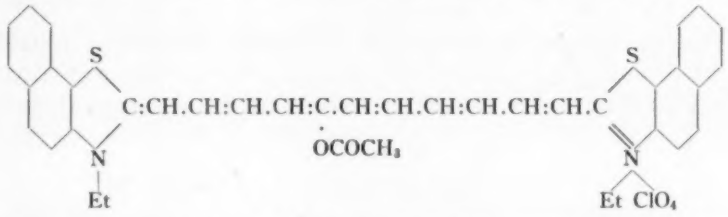
VIII 

similar sensitizing action (Fig. 1, *C*). The tetracarbocyanine derived from quinaldine etho p-toluenesulfonate, 13-acetoxy-1,1′-diethyl-2,2′-tetracarbocyanine perchlorate (IX) is a good

IX 

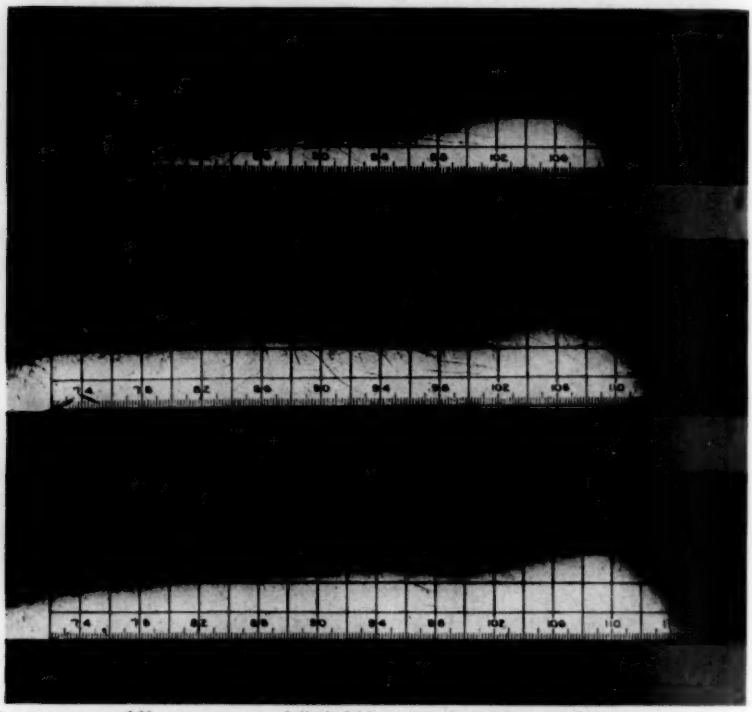
sensitizer with a maximum at about 9900A. (Fig. 1, *D*).

In the pentacarbocyanine series, V is a very strong sensitizer, conferring its maximum sensitiveness at about 10,500 A. (Fig. 2, *A*). The pentacarbocyanines derived from the naphthothiazoles, 11-acetoxy-2,2′-diethyl-5,6,5′,6′-dibenzothiapentacarbocyanine perchlorate (X) (Fig. 2, *B*) and 11-

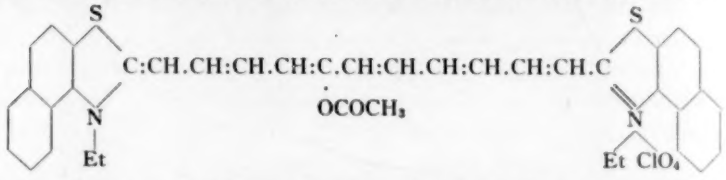
X 

acetoxy-2,2′-diethyl-3,4,3′,4′-dibenzothiapentacarbocyanine perchlorate (XI) (Fig. 2, *C*) are very similar in their action,

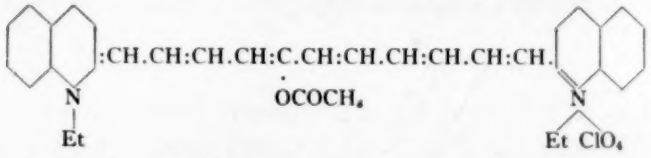
FIG. 2.



A spectrogram of V: 11-acetoxy-2, 2′-diethylthiapentacarbocyanine perchlorate
B spectrogram of X: 11-acetoxy-2,2′-diethyl-5,6,5′,6′-dibenzothiapentacarbocyanine perchlorate
C spectrogram of XI: 11-acetoxy-2,2′-diethyl-3,4,3′,4′-dibenzothiapentacarbocyanine perchlorate

XI 

the maximum sensitiveness occurring at about 10,900 A. 13-Acetoxy-1,1′-diethyl-2,2′-pentacarbocyanine perchlorate (XII) is a weaker sensitizer than X or XI and appears to have

XII 

a very indefinite maximum at about 11,200 A.

With the possible exception of III, all of these tetra- and especially penta-carbocyanines are difficult to prepare in a pure state. In many cases they are so unstable that they cannot be recrystallized, an almost complete loss of material resulting if this is attempted, even when acetone is used as solvent. This is doubtless due to the length of the conjugated polyene chains in the dye molecules.

The sensitizing bands of the pentacarbocyanines are extremely broad (compare Fig. 2, *A* to *D*). This effect may be due, in part, to the presence of carbocyanines with shorter chains, produced by the breakdown of the longer polymethine chains.

The detailed photographic application of the new sensitizers described in this paper will be discussed elsewhere, but it may be remarked that the use of plates sensitized with the new dyes has enabled several hundreds of new lines beyond 13,000 A. to be photographed in the spectra of the rare gases.[5]

[5] Private communication, Dr. W. F. Meggers.

Fog Dissipation.—(*Science Service.*) A report on a chemical method of fog dissipation by water-absorbing material to the American Philosophical Society, sponsor of the project, was made by PROF. E. L. BOWLES and H. G. HOUGHTON, JR., both of the Massachusetts Institute of Technology.

A course of preliminary research revealed the individual fog particles to range in size from two twenty-five-hundredths to one twenty-five-thousandth of an inch in diameter, the diameter of the smallest being only slightly greater than the wave-length of red light. Measurements were accomplished by allowing natural fog to drift across a flat glass slide on which the microscope was focussed while an extremely thin coating of grease on the slide caught individual particles and prevented the droplets from spreading.

Fog was found to be composed of particles of various sizes with one size usually predominating. In one of the earliest experiments it was found that a gram of calcium chloride powder was capable of clearing about three cubic meters of specific fog air at 20° C. This result indicated that dissipation was due to a lowering of the vapor pressure and not to a physical sweeping action. Thus, with a relative humidity of 97 per cent., drops of 40 microns diameter evaporated completely in 30 seconds. When the relative humidity was lowered to 85.6 per cent., drops of 50 microns in diameter evaporated in 10 seconds.

Investigation showed that small drops of calcium chloride removed more water vapor than large ones. It was necessary to design a special nozzle to produce droplets about 125 microns in diameter. A practical test was made on an actual fog using a 100-foot pipe fitted with the special nozzles at frequent intervals and suspended 30 feet above the ground. When the fog had completely enveloped the region, limiting the visibility to less than 300 feet, a fine spray of calcium chloride solution issued from the long pipe. Fog drifting through the chemical curtain began to precipitate, falling to the ground in the form of water drops. Within a few minutes objects more than 2000 feet away were clearly revealed along a path 100 feet wide and 30 feet high. This path was clear so long as the chemical barrage was operated.

Although calcium chloride is the only chemical thus far tested, any similar compound that is deliquescent, such as magnesium or zinc chloride, is a promising possibility.

C.

TESTS ON THE FULL SIZE MODEL ARCHES IN THE FRANKLIN INSTITUTE MUSEUM.

BY

FRANK N. KNEAS, C.E.,

Consulting Engineer, Philadelphia, formerly Chief Engineer for John T. Windrim, Architect.

INTRODUCTORY.

Some years ago, engineering thought tended toward statically determinate structures—toward three-hinged rather than toward hingeless arches.

Today, that trend is largely reversed. Study of indeterminate structures by the use of models has grown rapidly. In line with this advance and contributing to it, the model arches in the Department of Railroad Engineering in the Franklin Institute Museum, being built to full size and of structural materials, should play a helpful part.

Under one rail, the hingeless concrete arch spans fifty-five feet, and in line with it, the hingeless steel arch spans fifty-two feet. Under the other rail, the three-hinged concrete arch spans twenty-two feet, the one-hinged concrete arch spans twenty-six feet and the steel truss-girder spans fifty-eight feet.

The hinges of the three-hinged arch and of the one one-hinged arch have their pins resting in pedestals which are built of steel slabs, of stepped-up sizes, welded together. This is one of the first times that such pedestals have been used.

The live load on the arches consists of a modern locomotive, Baldwin No. 60,000. Its weight, complete with fuel and water and including the tender, is 701,000 pounds. Its weight as at present, without fuel and water is 532,000 pounds. Instruments measure the deflections at various points as the load moves slowly along the arches. These measurements allow comparisons between the actual and the theoretical for a live load movement of sixteen feet.

The dimensions, the properties, and the influence lines for all of the arch ribs are given on diagrams in a large frame beside the arches. They allow ready computation of the theoretical deflections.

The most complete load deflection tests on the arches were made as the locomotive was first installed, September 22, 1933. The locomotive was brought from a railroad siding, several blocks away, on temporary rails attached to timbers laid on the city streets. As it was installed, readings of the deflections were begun as the front wheels came on the arches and were continued for fifteen consecutive positions of the locomotive and of its tender. In the earlier positions, the rear portion of the locomotive, extending through an opening in the wall of the building, rested on the temporary cribbing outside.

A record of these tests, in the form of photostats of the arches with the locomotive in its fifteen different positions, is posted in a large frame beside the arches. Dot and dash lines on the photostats show the arch axes in their original positions, while dotted lines show the axes in their deflected positions. The vertical scale of the deflections is magnified to two hundred and fifty times the scale of the arches. The measured deflections are also given in figures in thousandths of an inch.

These lines and measurements on the different photostats show the deflection and recovery of the arches as the locomotive was moved along. From diagram to diagram, one can follow the minute movements of each arch, including the downward movement of the near quarter-point under the wheel loads and the upward movement of the far quarter-point at the opposite, unloaded, end of the arch. Comparisons are afforded between the deflection of the steel arch and that of the concrete arch and that of the steel truss-girder. Comparisons can be made between the deflection of the one-hinged arch and that of the three-hinged arch. The vertical movements of the abutments are also noted.

Diagrams of positions 1, 2, 4, 7, 9 and 11 have been reproduced in this paper, as well as the diagrams of the dimensions, the properties, and the influence lines.

HINGELESS CONCRETE ARCH—DEFLECTIONS AT THE CROWN.

It is interesting to trace the action of the hingeless arch by first observing the deflections at the crown for the successive loadings, and then noting the movements of the quarter points.

Diagram No. 1 shows the relative positions of the arches under the two rails, with the front wheels of the locomotive just coming upon them. The right front wheels are resting on the end of the hingeless concrete arch and the left front wheels on the small three-hinged arch. In this position, the deflection at the crown of the hingeless arch is slightly over one thousandth of an inch.

In positions No. 2, No. 4, and No. 7, as the loads advance, the deflection increases to five, then to thirteen, and then to the maximum of forty-four-thousandths of an inch.

In position No. 9, the load has passed partly off the arch and the deflection at the crown has receded to thirty thousandths of an inch.

In position No. 11, the load has passed almost entirely off the arch and the deflection at the crown has receded to only six thousandths. (Almost all of this remaining deflection at the crown can be attributed to the slight settlement of the abutments.)

HINGELESS CONCRETE ARCH—DEFLECTIONS AT THE QUARTER POINTS.

In position No. 1, it is seen that the deflection of the near quarter-point, under the wheel loads, is slightly over five times that of the crown, while at the far quarter-point, unloaded, the deflection is upward.

In positions No. 2 and No. 4, similar movements are noted, the loaded quarter-point downward, and unloaded, upward.

In position No. 7, the wheel loads are fairly well balanced about the crown and the deflections of the quarter-points are almost equal.

As the loads pass farther along the arch, the deflection of the second quarter-point increases and that of the first decreases.

In position No. 11, the deflection of the first quarter-point decreases to almost zero,—when the displacement of the arch as a whole is considered, due to the vertical settlement of the abutments.

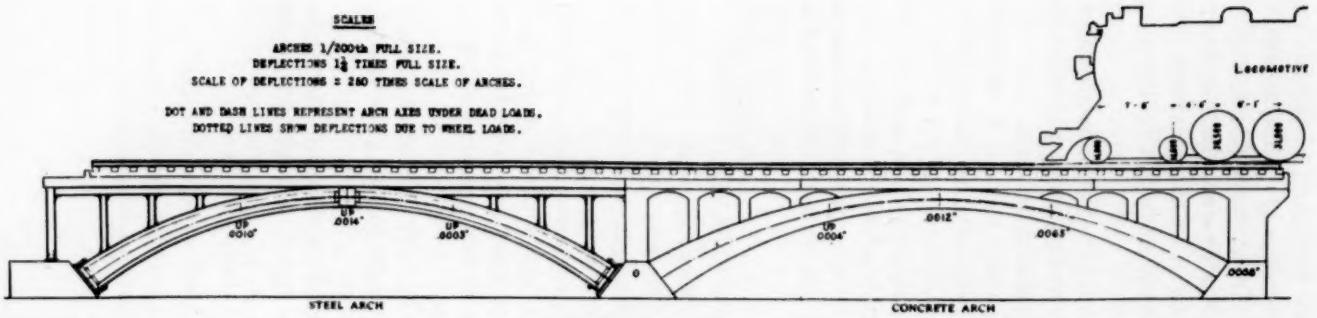
HINGELESS STEEL ARCH.

In position No. 9, the movement of the loaded quarter-point downward and of the unloaded quarter-point upward can be noted.

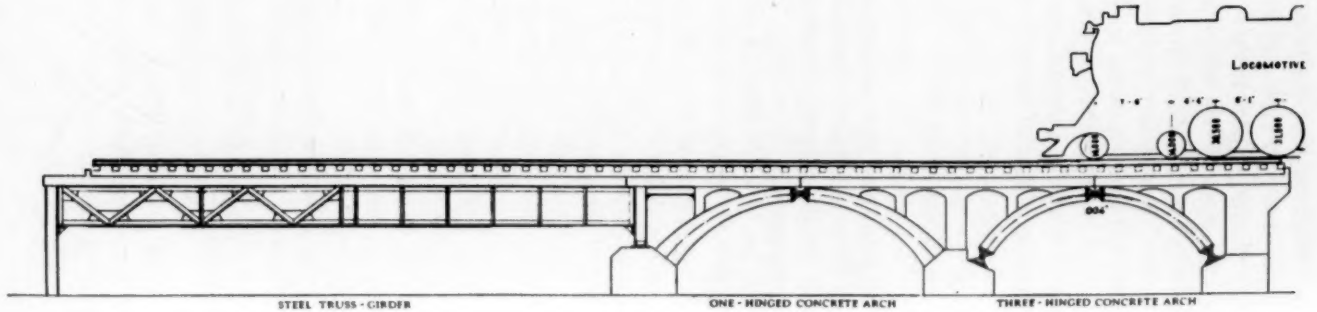
SCALES

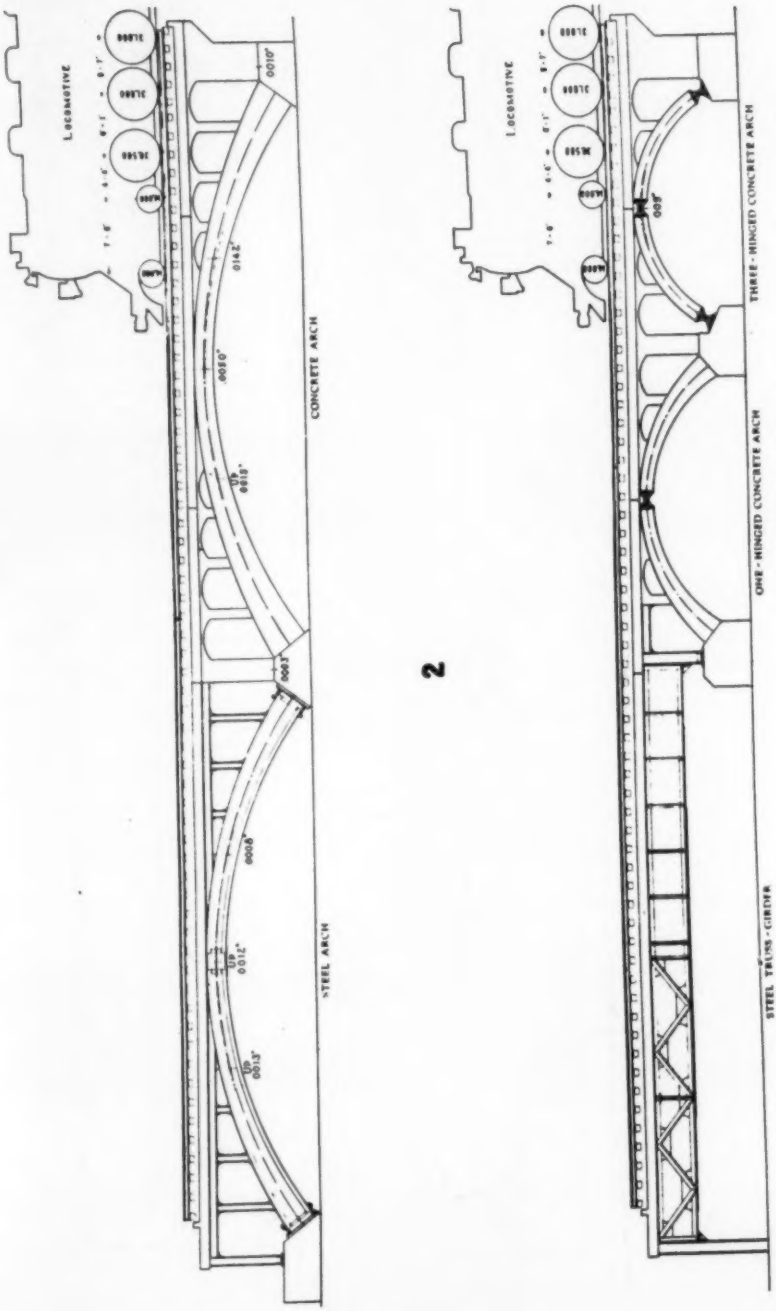
ARCHES 1/200th FULL SIZE.
DEFLECTIONS 1½ TIMES FULL SIZE.
SCALE OF DEFLECTIONS = 280 TIMES SCALE OF ARCHES.

DOT AND DASH LINES REPRESENT ARCH AXES UNDER DEAD LOADS.
DOTTED LINES SHOW DEFLECTIONS DUE TO WHEEL LOADS.



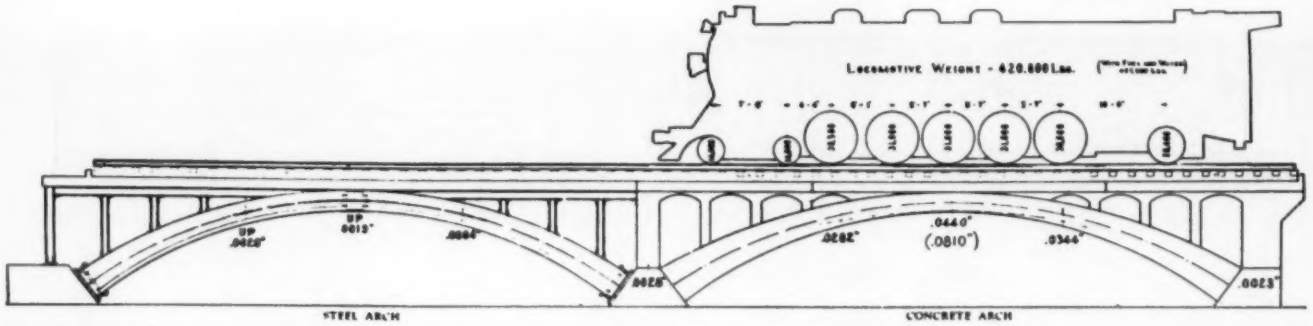
1



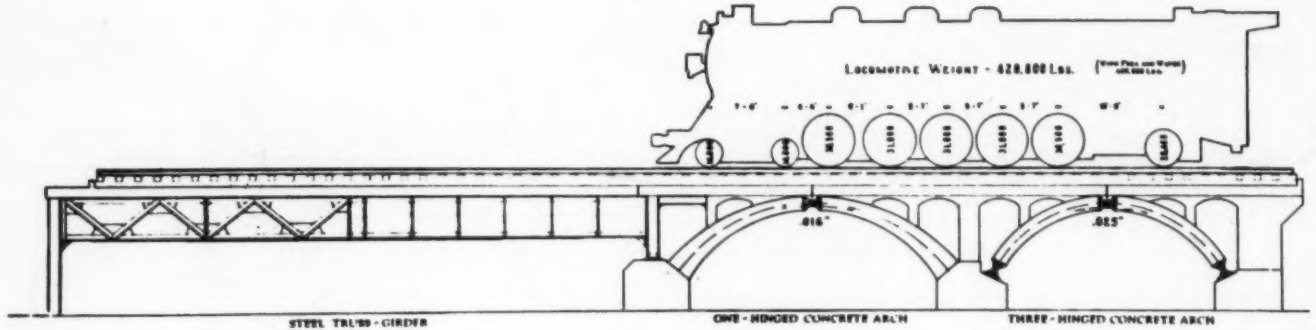

Locomotive
CONCRETE ARCH
STEEL ARCH
THREE-HINGED CONCRETE ARCH
ONE-HINGED CONCRETE ARCH
STEEL TRUSS-GIRDER

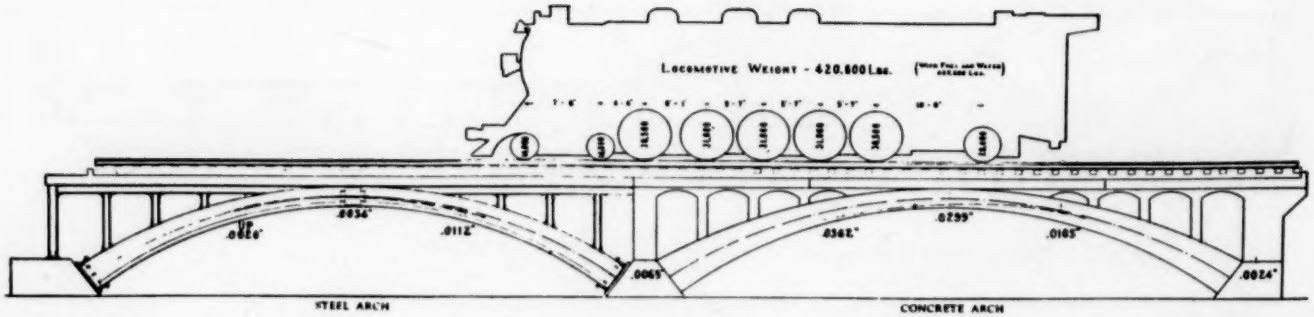
2

Locomotive Weight - 420,000 Lbs.
CONCRETE ARCH
STEEL ARCH
Locomotive Weight - 420,000 Lbs.
THREE - HINGED CONCRETE ARCH
ONE - HINGED CONCRETE ARCH
STEEL TRUSS - GIRDER

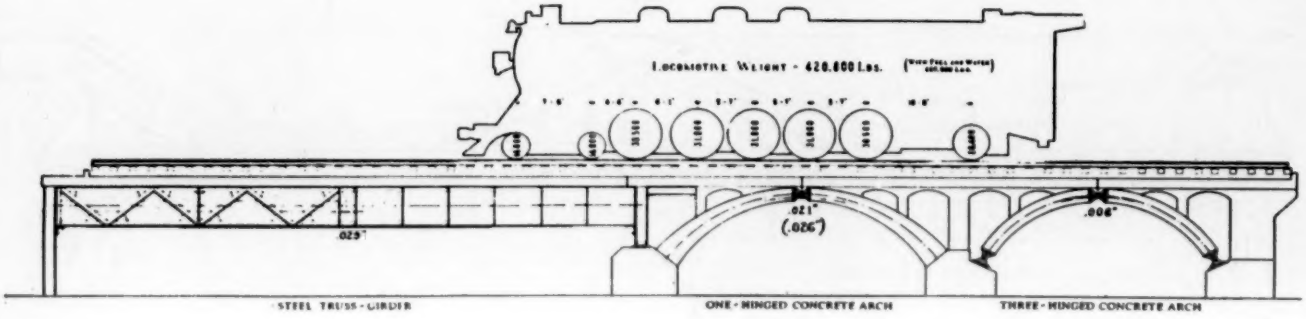

LOCOMOTIVE WEIGHT - 420,000 Lbs.
UP .0028"
UP .0013"
.0064"
.0028"
.0282"
.0440"
(.0810")
.0344"
.0023"
STEEL ARCH
CONCRETE ARCH

7


LOCOMOTIVE WEIGHT - 420,000 Lbs.
.016"
.015"
STEEL TRUSS - GIRDER
ONE - HINGED CONCRETE ARCH
THREE - HINGED CONCRETE ARCH


LOCOMOTIVE WEIGHT - 420,800 Lbs.
.0056"
.0112"
.0059"
.0362"
.0299"
.0165"
.0024"
STEEL ARCH
CONCRETE ARCH

9


LOCOMOTIVE WEIGHT - 420,800 Lbs.
.029"
.021"
(.026")
.008"
STEEL TRUSS-GIRDER
ONE-HINGED CONCRETE ARCH
THREE-HINGED CONCRETE ARCH

STEEL ARCH
CONCRETE ARCH
STEEL TRUSS-ORDER
ONE-HINGED CONCRETE ARCH
THREE-HINGED CONCRETE ARCH

11

Comparing the Diagrams for positions No. 4, No. 7, and No. 11, it will be seen that the deflections of the steel arch are greater than those for the concrete arch. This is to be expected because the steel arch is only three-quarters as deep in section at the haunch and in general is not as stiff as the concrete arch.

In position No. 11, a contrast is afforded between the deflection of the crown of the steel arch and that of the center of the steel truss-girder, .074″ as compared with .303″. In position No. 15, not reproduced here, the deflection of the crown of the steel arch was .084″ as compared with .433″ for the center of the steel girder, the locomotive being farther advanced on each.

FIXITY OF THE ABUTMENTS.

The abutments at the ends of the arches are founded on and anchored to groups of vertical steel pipe piles driven to rock. These in themselves form very firm foundations. In addition the abutments are anchored together by steel rods embedded in concrete girders beneath the floor. To minimize the movement that would be caused by the stretch in the bars, the abutments were solidly bedded against the undisturbed gravel soil at each end. The lengthwise movements of the abutments and their rotation are therefore very much restrained.

Of course, since the abutments are of reinforced concrete, they have the elasticity of that material and there will be some elastic deformation in the abutment due to the tension and compression of the arch rib where it connects to each abutment, which would be in addition to such slight movements as might occur in the abutments themselves.

The maximum vertical movement, shown in the diagrams, is for the center abutment (in position No. 11) and is .0078″; and for the end abutment it is .0024″ (in position No. 9).

EFFECT OF CONTINUITY.

The hingeless concrete arch and the hingeless steel arch are fixed at the ends and their continuity, through the same center abutment, resulted in a slight upward deflection of the unloaded steel arch when the wheel loads came on the concrete arch. This upward deflection, however, amounted to only

.002″, when the downward deflection of the concrete arch was .044″, both deflections being measured at the crown. The upward movement of the crown of the steel arch was therefore only about 4 per cent. of the downward movement of the concrete arch. While this shows the effect of continuity, it also shows a considerable degree of fixity in the abutments.

The three-hinged concrete arch and the one-hinged concrete arch also rested against a common central abutment, but here the continuity was broken by the end hinge of the three-hinged arch and no movement was detected at the crown of the one, when the load came on the other.

EFFECT OF THE DECK STRUCTURES.

As is well recognized, the deck structures above arch ribs add to the rigidity of the arches and reduce their deflections. Expansion joints in the deck structures reduce these stiffening effects.

Therefore, in the following comparisons between recorded and calculated deflections, it is well to note that the deck structure of the steel arch is not as heavy nor as rigidly connected to the rib as is the deck of the concrete arch. There is no expansion joint in the deck of the steel arch. There is no expansion joint at the center of the deck of the concrete arch, but there is one at about each quarter point. In the one-hinged arch, and also in the three-hinged arch, there is an expansion joint in the deck just over the crown.

COMPARISON BETWEEN RECORDED AND CALCULATED DEFLECTIONS.

In the comparisons between the recorded deflections and the calculated deflections, it is believed that the differences may be attributed, in general, to the restraining action of the deck with possibly some additional restraining action due to the continuity of the arches and to the distributing effect of the rails.

The recorded deflection of the center of the hingeless steel arch is .074″, as compared with a corresponding calculated deflection of .085″.

The recorded deflection of the center of the hingeless concrete arch is .044″ as compared with a corresponding calculated deflection of .081″, or .070″, depending on the

modulus of elasticity which is assumed for the concrete. It is probable from other tests, that the modulus of elasticity, in pounds per square inch, for this 1–1½–3 concrete, which was nearly a year old when the locomotive was installed, was between 3,625,000 and 4,143,000, corresponding to $n=8$ and $n=7$, respectively, the modulus for steel being taken at 29,000,000.

In the above comparisons, it is evident that the deck of the concrete arch had a greater restraining effect on its deflection than the deck of the steel arch. The large area of deck bonded to the rib of the concrete arch evidently reduced the deflection by reducing the rib-shortening as well as by reducing the bending.

The recorded deflection of the center of the one-hinged arch is .021″, as compared with a corresponding calculated deflection of .026″.

The recorded deflection of the center of the three-hinged arch is .028″, as compared with a corresponding calculated deflection of .041″.

EFFECT OF RIB-SHORTENING.

Due to compressive stresses along the axis, the arch rib compresses and becomes shorter. This effect is in addition to the effect of direct bending due to the loads, and it sometimes exercises a great influence, especially on crown moments and on deflections.

It is sometimes inferred that the effect of rib-shortening is so small that it can be ignored, except for very flat arches. This seems to be an incorrect inference. The hingeless steel arch and the hingeless concrete arch in the Franklin Institute cannot be classed as very flat. Comparing them with a group of arches taken at random, they were found to be of an average ratio of rise to span. Yet for these arches, the following effects of rib-shortening are found.

The horizontal thrusts for the hingeless arches, calculated without taking into account the rib-shortening effect, are about 16 per cent. too large, for any type of loading.

The moments at the crown, for distributed loads, calculated without taking into account the rib-shortening effect, are about 50 per cent. too small.

The deflections at the crown, for distributed loads, calculated without taking into account the rib-shortening effect, are only about one-sixth of the true deflections.

These arches particularly emphasize the effect of rib-shortening, because the arch ribs are so stiff in comparison to the span and rise in each case.

CALCULATED DEFLECTIONS.

Equations.

In calculating the deflections of the hingeless arches for comparison with the recorded deflections, the equations given by Turneaure and Maurer[1] were used. The temperature during the test was considered constant. Each half of the arch was divided into ten divisions of such length that the ratio of the moment of inertia of each division to its length was a constant so that q became unity.

The equations then become, for the *Hingeless Arch*,

$$(1)\quad H_c = \frac{\sum_A^C (m_R + m_L)\ \sum_A^C y - \sum_A^C (m_R + m_L) y (10)}{2\left[\ 10\left(\ \sum_A^C y^2 + \frac{I}{ds}\sum_A^C \frac{ds\cos\alpha}{A}\right) - (\sum_A^C y)^2\right]},$$

$$(2)\quad V_c = \frac{\sum_A^C (m_R - m_L) x}{2\sum_A^C x^2},$$

$$(3)\quad M_c = -\frac{\sum_A^C (m_R + m_L) + 2Hc\ \sum_A^C y}{2(10)},$$

$$(4)\quad M_x = M_c + H_c y + V_c x + m_L \quad \text{(left side)},$$

$$(5)\quad Dc = \sum_A^C\left[-\frac{M_x x ds}{EI} + \frac{f dy}{E} - \frac{f x ds}{E\rho}\right].$$

For those who wish to investigate the one-hinged arch in the Franklin Institute Museum, the writer submits the following, as developed and used by him in comparing the deflections.

---

[1] "Principles of Reinforced Concrete Construction," Turneaure and Maurer (Fourth Edition).

One-Hinged Arch.

$$(6) \qquad H_c = -\frac{\sum_A^C m_L y + \sum_B^C m_R y}{2\sum_A^C \left[y^2 + \frac{I}{ds}\sum_A^C \left(\frac{ds\cos\alpha}{A} + \frac{yds}{A\rho} \right) \right]},$$

$$(7) \qquad V_c = \frac{\sum_A^C m_R x - \sum_B^C m_L x}{2\sum_A^C x^2},$$

$$(8) \qquad M_x = H_c y + V_c x + m_L,$$

$$(9) \qquad D_c = \sum_A^C \left[-\frac{M_x x ds}{EI} + \frac{f dy}{E} - \frac{f x ds}{E\rho} \right].$$

Notation:

H_c = thrust at the crown.
V_c = shear at the crown.
M_c = bending moment at the crown.
D_c = deflection of crown.
ds = length of divisions of the arch ring measured along the arch axis.
N = number of divisions—10 for each half of the arch ring.
dx = length of a division of the arch ring projected on the horizontal axis.
dy = length of a division of the arch ring projected on the vertical axis.
x = horizontal distance from center of axis at crown to center of division of the arch ring.
y = vertical distance from center of axis at crown to center of division of the arch ring.
A = area of cross section. In the case of the reinforced concrete arch, this includes area of concrete plus 8 times area of steel. (n, taken as 8.)
I = moment of inertia of each section.
m_R & m_L = bending moments at points in the Right and Left cantilever halves of the arch due to external loads. These moments are negative.
α = inclination of arch axis at any point.
ρ = radius of curvature of arch axis at any point.
f = average compressive fibre stress at any point.

l = span length.
s = length of arch axis.
h = rise.
The temperature is assumed to be constant. The ten divisions each side of the center line were laid out so that ds/I = a constant.
A & B = intersections of arch axis with bearings at left and right abutments respectively.
C = center of arch axis at crown.
M_x = bending moment at a section at x distance from the crown.

PROPERTIES OF THE HINGELESS CONCRETE ARCH RIB.

To show the development of the influence lines, from which the thrusts, shears, moments and deflections can be derived, the properties and dimensions of the hingeless concrete arch rib are given in Table A. From this table, the influence lines can be drived by the formulas previously noted.

DERIVATION OF THE INFLUENCE LINES.

The influence lines for the hingeless concrete arch are given in Table A.

Equation 1 gives the value for the horizontal thrust as follows:

$$(1)\quad H_c = \frac{\sum_A^C(m_R + m_L)\sum_A^C y - \sum_A^C(m_R + m_L)y(10)}{2\left[10\left(\sum_A^C y^2 + \frac{I}{ds}\sum_A^C \frac{ds\cos\alpha}{A}\right) - (\sum_A^C y)^2\right]}.$$

For a load of unity, at an infinitely small distance to the right of the center of the arch, there will be no m_L, and the term $\sum_A^C(m_R + m_L)$ becomes equal to the summation of unity times x, or $(\sum_A^C x)$, and from the properties given in Table A, this is found to be 99.637.

The

$$\sum_A^C y = 15.346,$$
$$\sum_A^C y^2 = 57.886,$$
$$\frac{I}{ds} = \frac{1}{.748} = 1.337,$$
$$\sum_A^C \frac{ds\cos\alpha}{A} = \sum_A^C \frac{dx}{A} = 4.143,$$
$$\sum_A^C(m_R + m_L)y(10) = 10\sum_A^C xy = 2776.40,$$
$$(\sum_A^C y)^2 = (15.346)^2 = 235.61.$$

Inserting these values in the equation, $H_c = 1.564$. This value does not omit the effect of rib-shortening.

If, in the denominator, the term $I/ds \sum_A^C ds \cos \alpha/A$, which represents the effect of rib-shortening, is neglected, the denominator becomes smaller and the value for H_c becomes about 16 per cent. too large, as indicated by the dotted line for the H_c influence line.

In the equation for the moment at the crown,

$$M_c = - \frac{\sum_A^C (m_R + m_L) + 2H_c \sum_A^C y}{2(10)},$$

the term H_c occurs in the numerator, and if it is too large, on account of neglecting the rib-shortening, it will result in the positive values for the moment at the crown being too small and the negative values being too large, and for loads distributed along the length of the arch, the summation for the total moment at the crown will be about 50 per cent. too small.

With rib-shortening, for a unit load at the right of the crown,

$$M_c = - \frac{-99.637 + 2(1.564)(15.346)}{20} = +2.581.$$

Deflection at the Crown.

Equation 5 gives the value for the deflection at the crown.

$$D_c = \sum_A^C \left[- \frac{M_x x ds}{EI} + \frac{f dy}{E} - \frac{f x ds}{E\rho} \right].$$

The terms fdy/E and $fxds/E\rho$ are very minor elements of the effect of rib-shortening. Their values are very small and, being of opposite sign, their totals are still smaller. In general they may be ignored. For distributed wheel loads on the hingeless concrete arch, their total effect on the deflection D_c is .000,02″.

The major effect of rib-shortening is included in the value of M_x in the term $M_x xds/EI$. M_x, as shown in equation (4), includes both H_c and M_c, whose values will be in error if the effect of rib-shortening is ignored.

When the incorrect values of H_c and M_c are used to find the deflection at the crown, the results are very erratic and misleading.

The dotted influence line for the deflection at the crown, (D_c), when compared with the solid line, shows how far the values without rib-shortening depart from the correct values.

For a load of 10,000 pounds at the crown, the calculated deflection of the crown, including the effect of rib-shortening, is .00903″, while without rib-shortening, the calculated deflection is only .00368″.

For a load at the quarter-point, the deflection at the crown, calculated without rib-shortening, is actually upward, but the true deflection of the crown is downward.

This downward deflection of the crown for a load at the quarter-point is confirmed by the tests.

In positions No. 1, No. 2, and No. 4, for example, with varying loads on and about the quarter-point, the deflection of the crown is in each case downward. This is true for all similar positions for both the concrete and the steel arch.

From the influence lines, by summation, it is found that for loads distributed along the arch, the deflection at the crown, calculated without the effect of rib-shortening, is only about one-sixth of the true deflection.

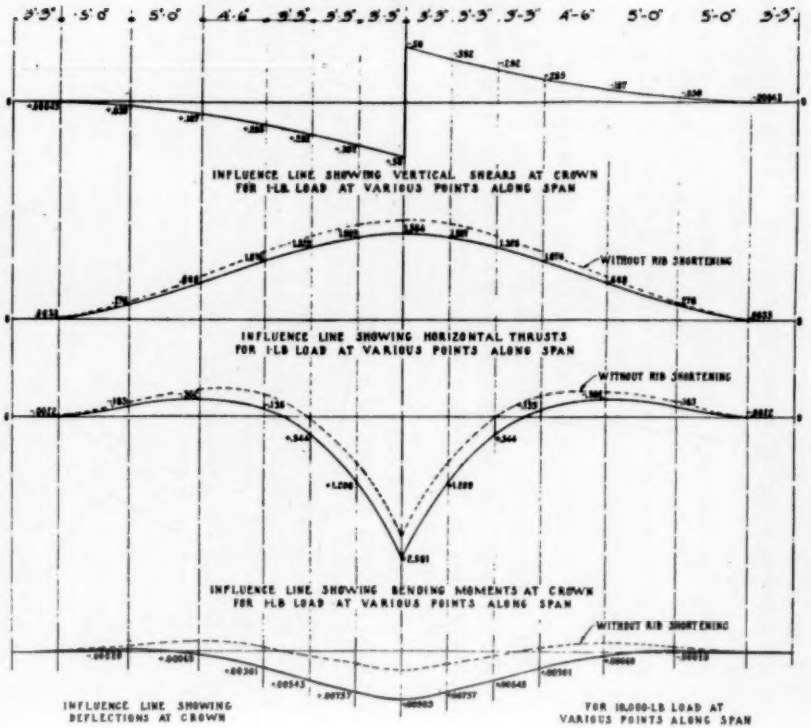
VERIFICATION OF THE CALCULATED DEFLECTION.

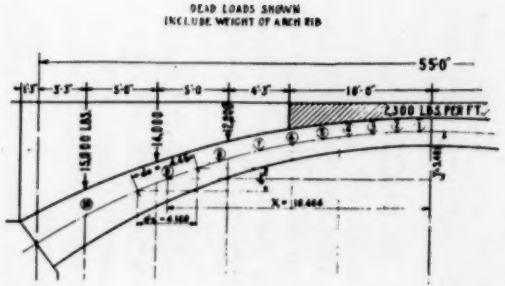
An approximate verification of the true deflection was made by calculating the shortening of the rib by direct compression, on the basis of the average compressive stress along its length.

It was assumed that the axis of the shortened rib approximated in form the arc of a circle and that the ends of the arc coincided with the ends of the original axis. The shorter arc, on the same length of chord, came within the arc of the original axis. The distance between the two arcs at the crown was computed. The result showed that the effect of rib-shortening could not be ignored and was an approximate verification of the deflection found by use of the equations, including the effect of rib-shortening.

A

INFLUENCE LINES
HINGELESS CONCRETE ARCH


INFLUENCE LINE SHOWING VERTICAL SHEARS AT CROWN FOR 1 LB LOAD AT VARIOUS POINTS ALONG SPAN
WITHOUT RIB SHORTENING
INFLUENCE LINE SHOWING HORIZONTAL THRUSTS FOR 1 LB LOAD AT VARIOUS POINTS ALONG SPAN
WITHOUT RIB SHORTENING
INFLUENCE LINE SHOWING BENDING MOMENTS AT CROWN FOR 1 LB LOAD AT VARIOUS POINTS ALONG SPAN
WITHOUT RIB SHORTENING
INFLUENCE LINE SHOWING DEFLECTIONS AT CROWN
FOR 10,000-LB LOAD AT VARIOUS POINTS ALONG SPAN



PROPERTIES OF CONCRETE ARCH RIB

SPAN - 55'0" RISE - 8'0" RADIUS OF ARCH AXIS - 36'4½"
CROWN - WIDTH - 2'3" DEPTH - 2'6" HAUNCH - WIDTH - 2'8" DEPTH - 4'1"
CONCRETE - 1:2:4 MIX. $n = 8$
REINFORCING - 9 - 1" SQ. BARS - TOP AND BOTTOM - CENTER OF BARS - 2" FROM FACE
$\frac{A_s}{A_c} = 0.746$ (CONSTANT) $A = A_c + nA_s$

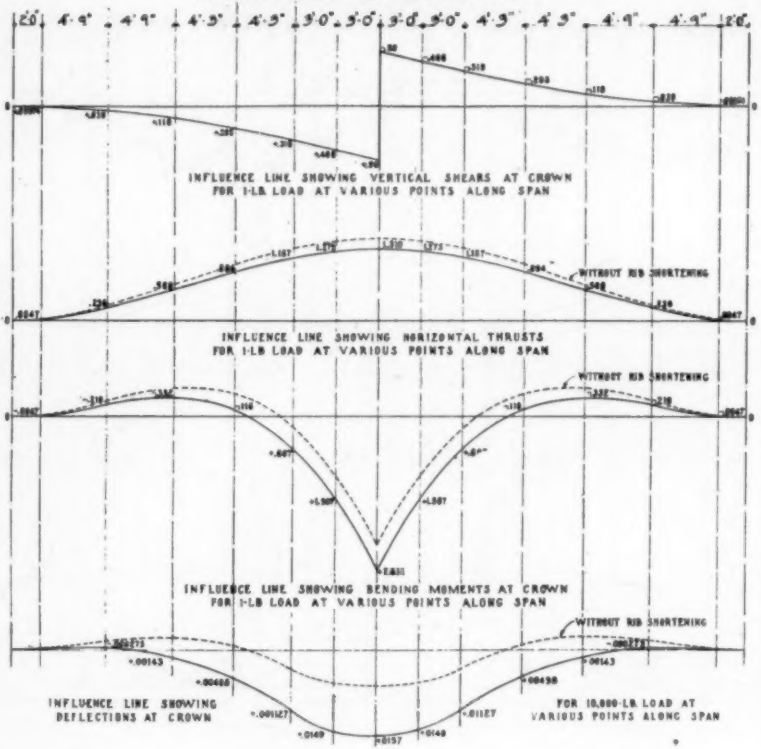
ALL VALUES IN FEET

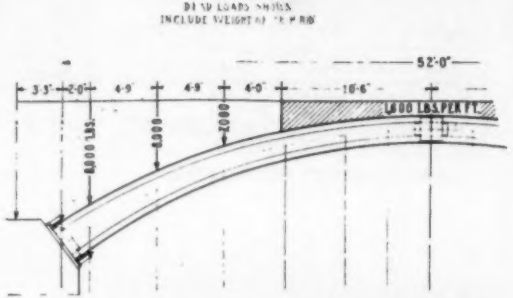
PANEL	d_0	d_n	x	y	xy	x^2	y^2	A
1	1.60	1.600	0.800	0.0063	0.005	0.640	0.00004	5.39
2	1.62	1.618	2.409	0.058	0.140	5.803	0.00336	5.40
3	1.69	1.684	4.051	0.163	0.660	16.411	0.0266	5.47
4	1.79	1.775	5.792	0.534	1.935	33.547	0.1116	5.57
5	1.95	1.927	7.645	0.583	4.457	58.446	0.3398	5.70
6	2.19	2.148	9.684	0.939	9.093	93.780	0.8817	5.90
7	2.56	2.487	12.012	1.450	17.417	144.288	2.1025	6.20
8	3.21	3.058	14.784	2.218	32.793	218.567	4.9185	6.69
9	4.46	4.160	18.404	3.481	64.044	338.707	12.1174	7.36
10	8.02	7.035	24.056	6.114	147.078	578.691	37.3810	8.87
Σ	29.09	27.500	99.637	15.346	277.640	1488.880	57.0836	

B

B

INFLUENCE LINES
HINGELESS STEEL ARCH


INFLUENCE LINE SHOWING VERTICAL SHEARS AT CROWN
FOR 1-LB LOAD AT VARIOUS POINTS ALONG SPAN
WITHOUT RIB SHORTENING
INFLUENCE LINE SHOWING HORIZONTAL THRUSTS
FOR 1-LB LOAD AT VARIOUS POINTS ALONG SPAN
WITHOUT RIB SHORTENING
INFLUENCE LINE SHOWING BENDING MOMENTS AT CROWN
FOR 1-LB LOAD AT VARIOUS POINTS ALONG SPAN
WITHOUT RIB SHORTENING
INFLUENCE LINE SHOWING
DEFLECTIONS AT CROWN
FOR 10,000-LB LOAD AT
VARIOUS POINTS ALONG SPAN

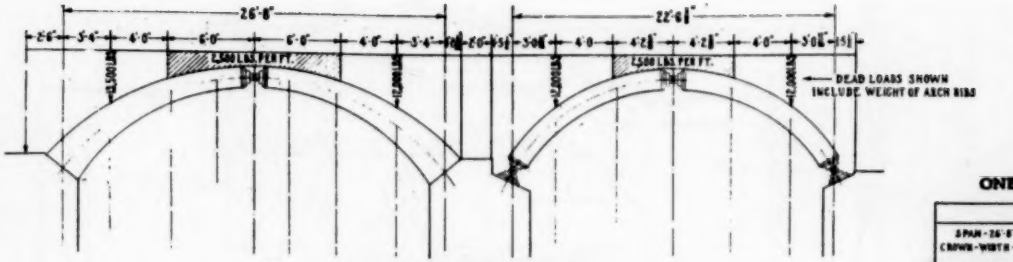


PROPERTIES OF STEEL ARCH RIB

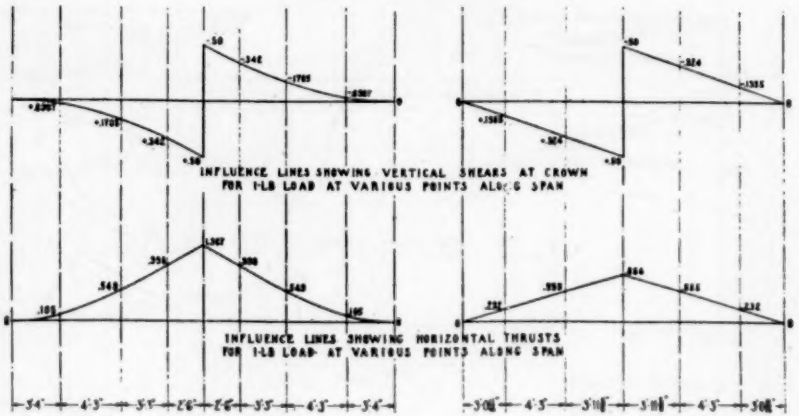
SPAN - 52'-0" RISE - 8'-6" RADIUS OF ARCH AXIS - 45'-9"
CROWN - DEPTH - 2'-0" B TO B OF ANGLES HAUNCH - DEPTH - 3'-0" B TO B OF ANGLES
SECTION - { 1 WEB PLATE
4 ANGLES - 6"x6"x ½"
ds = 0.50 (CONSTANT)
ALL VALUES IN FEET

PART	ds	dA	x	y	xy	x²	y²	A
1	2.04	2.039	1.020	0.012	0.0122	1.040	0.00014	0.318
2	2.07	2.061	3.065	0.108	0.3310	9.394	0.01166	0.319
3	2.12	2.109	5.158	0.295	1.8574	26.605	0.0420	0.320
4	2.20	2.169	7.296	0.613	4.4725	53.232	0.3758	0.321
5	2.35	2.293	9.528	1.050	10.0044	90.786	1.1025	0.324
6	2.57	2.473	11.913	1.673	19.9305	141.920	2.7989	0.327
7	2.87	2.707	14.505	2.475	35.8959	210.395	6.1256	0.331
8	3.26	2.932	17.358	3.501	62.3326	310.308	12.8953	0.336
9	3.76	3.314	20.522	4.111	104.8879	421.152	26.1223	0.342
10	4.60	3.843	24.114	7.245	174.7050	581.485	52.4900	0.355
Σ	27.84	26.000	114.479	22.083	413.6329	1846.309	101.5643	⊠

C



INFLUENCE LINES


INFLUENCE LINES SHOWING VERTICAL SHEARS AT CROWN FOR 1-LB LOAD AT VARIOUS POINTS ALONG SPAN
INFLUENCE LINES SHOWING HORIZONTAL THRUSTS FOR 1-LB LOAD AT VARIOUS POINTS ALONG SPAN

ONE-HINGED
REINFORCED CONCRETE ARCH

THREE-HINGED
REINFORCED CONCRETE ARCH

ONE-HINGED CONCRETE ARCH

PROPERTIES OF ARCH RIB

SPAN-26'8" RISE-6'0" RADIUS OF ARCH AXIS-16'0"
CROWN-WIDTH-2'5" DEPTH-1'6" HAUNCH-WIDTH 2'5" DEPTH-2'10"
CONCRETE - 1:2½:3 MIX n = 8
REINFORCING-8-1"Ø RODS TOP AND BOTTOM-CENTER OF RODS 2" FROM FACE
ϕ = 2.107 (CONSTANT) A = Ac + nAs

ALL VALUES IN FEET

PNTS	dx	dw	x	y	xy	x²	y²	A
1	1.78	1.776	0.890	0.026	0.021	0.792	0.0006	3.56
2	1.89	1.864	2.713	0.222	0.602	7.360	0.0493	3.86
3	2.22	2.128	4.715	0.681	3.211	22.231	0.4636	4.18
4	3.06	2.750	7.179	1.625	11.666	51.538	2.6406	4.81
5	6.50	4.887	11.130	4.263	47.473	124.010	18.173C	5.90
Σ	15.45	13.233	26.639	6.819	62.973	207.931	21.3275	

THREE-HINGED CONCRETE ARCH

PROPERTIES OF ARCH RIB

SPAN-22'-6½" RISE-6'-1" RADIUS OF ARCH AXIS-16'-10½"
WIDTH-2'-5" DEPTH-1'-0"
CONCRETE - 1:2½:3 MIX n = 8
REINFORCING-8-1"Ø RODS-TOP AND BOTTOM-CENTER OF RODS 2" FROM FACE
ϕ = 4.166 (CONSTANT) AREA = Ac + nAs = 3.623 SQ.FT.

ALL VALUES IN FEET

PNTS	dx	dw	x	y	xy	x²	y²	mx sq dx
1	2.737	2.717	1.366	0.092	0.096	1.866	0.085	0.189
2	2.737	2.596	4.037	0.646	2.606	16.299	0.417	1.864
3	2.737	2.350	6.523	1.706	11.130	42.625	3.110	5.668
4	2.737	2.010	9.730	3.388	29.551	76.205	11.450	13.565
5	2.737	1.546	10.861	5.459	57.236	111.127	29.805	25.647
Σ	13.685	11.276	31.203	11.299	101.025	248.122	44.484	45.883

PROPERTIES AND INFLUENCE LINES.

The properties and influence lines for the hingeless concrete arch are given in Plate A, for the hingeless steel arch in Plate B, those for the one-hinged arch and for the three-hinged arch in Plate C.

The steel truss-girder, one half of which illustrates a plate-girder, and the other half a truss, has its flange angles continuous. Each flange is built up of two 6″ x 6″ x ¾″ angles, with two 14″ x ¾″ cover plates. The distance back to back of flange angles is 4′–0′2″, the web is 48″ x ½″.

All diagrams are to scale, the dimensions between wheel centers can be used as a guide to determine the other dimensions. The properties and influence lines will allow students of arch theory to compute arch stresses and deflections for the different positions of the locomotive during installation. Since the locomotive moves forward and backward along the arches a distance of about sixteen feet, an interesting opportunity is given for further investigations of arch deflections and, by the use of extensometers, of stresses; the deflections and stresses in the rails and splices may also be measured.

ACKNOWLEDGMENTS.

The writer wishes to express his appreciation of the interest shown by Dr. Howard McClenahan, Secretary of the Franklin Institute, and by the late John T. Windrim, architect, in directing the installation of these arches, and to extend his thanks to Samuel Napp, Viggo Hansen, and Harry Stumpf, fellow engineers in the office of Mr. Windrim, for their cordial coöperation in the design of the arches and the checking of the calculations and of the diagrams in this paper, and to Professor George E. Beggs for his kind review and suggestions.

B_4C.—The story of a new abrasive recently was told to the Electrochemical Society by R. R. RIDGEWAY, research engineer for the Norton Co. This new product is known as boron carbide and it is made in a manner similar to that for the manufacture of silicon carbide, using a resistance type furnace with its graded temperature zones. This new carbide is produced in the form of freely developed crystals and has an average composition closely approximating the formula B_4C.

The first step in the manufacture of boron carbide is the dehydration of the commercial boric acid. The anhydrous glass then is combined with a high purity coke in a special resistance furnace. The reaction takes place at 2,500 to 2,600° C. The intrinsic hardness of B_4C exceeds that of SiC (silicon carbide). The boron carbide is inert in all solutions of acids and alkalis, both concentrated and dilute. Industrially, B_4C is used for drilling cemented tungsten carbide die nibs; nozzles for abrasive blasting; wire drawing dies and the like. C.

Radiating Comfort.—(*Science Service.*) Does it sound possible that you could sit in a room into which air is coming at a temperature of 12 degrees above zero and feel comfortable? Or sit in the same room in which warm air at 112 degrees was entering with the same comfort? All this was demonstrated in the Research Laboratories of the Westinghouse Electric and Manufacturing Company.

The secret of such bodily comfort under circumstances so unusual depends upon a regulation of the amount of heat radiated to and from the body. While the body temperature is about 98 degrees the outside temperature of the clothing is nearer 80 degrees. Thus, to make one feel comfortable when the incoming air is cold it is only necessary to heat the walls of the room up to 80 degrees and prevent radiation losses. For a cooling effect the trick is to lower the temperature of the walls to about 50 degrees. Then, although the air coming in was heated to 112 degrees, as in midsummer, one felt comfortable because the body was able to radiate easily to the cooler walls.

By this system it is possible to stay cool in summer even with the window open and the hot air pouring in. Even in winter, frigid air can enter through open windows without discomfort. The temperature of the walls is lowered or raised either by inlaid electric wires or by concealed pipe coils through which either hot or cold water can be passed. The walls can properly be of metal sheeting. One hitch, at present, is the sweating of the cool walls in summer when the temperature is high and the air contains much moisture. At present concealed troughs in the baseboard take care of this condition. C.

SOME VISIBILITY TESTS ON LIGHTED AND UNLIGHTED HIGHWAYS.

BY

PARRY MOON* AND R. C. WARRING.†

SYNOPSIS.

The paper discusses the results of over 5,000 tests made to determine the effect of various factors on the distance at which the driver of a motor vehicle can see a pedestrian. The work was done as part of the Massachusetts Highway Accident Survey, Project No. 3493 of the Civil Works Administration. The principal conclusions are:

(*a*) The safety of a pedestrian walking along a highway at night can be greatly increased by the use of a small area of white (such as a handkerchief) or by reflector buttons. The visibility distance is increased approximately 50 per cent. by the former and 100 per cent. by the latter.

(*b*) Maximum safe speeds at night on unlighted highways are approximately 30 m.p.h. when there is glare from passing cars and 40 m.p.h. when there is no glare.

(*c*) Type of pavement and speed of car have little effect on visibility distance on unlighted roads.

(*d*) An increase in headlamp c.p. above 32 seems advisable.

(*e*) Depressing the headlamp beams of passing cars reduces visibility distance.

(*f*) Highway lighting does not increase visibility distance appreciably unless the average luminosity of the pavement is above the chromatic threshold (order of 0.05 lumen/ft.^{2}).

1. INTRODUCTION.

The tests were made as part of the Massachusetts Highway Accident Survey, Civil Works Administration Project No. 3493, supervised by the Massachusetts Institute of Technology and conducted during the winter and spring of 1934. The purpose of the investigation was to determine by actual test the distance at which the driver of a motor vehicle can see a pedestrian who is walking along the side of the highway at night.[1] It is hoped that the collection of a large number of such data obtained under a wide variety of conditions will be

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[1] This quantity will be called the *visibility distance* and will be expressed in feet.

of use in the intelligent attempt to reduce the loss of life on highways at night.

The best previous work on this subject appears to be that of Dickinson and Allen,[2] which was done in 1927–28 at the Bureau of Standards. Though their work is of unquestionable value, it is confined to *unlighted* roads. The large number of accidents occurring on lighted streets and the present agitation for the lighting of important state highways emphasize the need for extensive research regarding safety on lighted roads. Dickinson and Allen suggest: "One of the most immediate practical needs, however, seems to be a study of the effect of various types of artificial highway-lighting on safe visibility. Almost unquestionably certain conditions exist under which some types of fixed highway-illumination introduce real hazards as compared with headlighting alone, even in the present state of headlight inefficiency."

Harris and Diggs,[3] have recently devised a test procedure to show the advantages of street lighting in increasing visibility distance. A stationary car is used. That the conditions of the test bear little relation to actual driving conditions may be inferred from their statement:

"To carry out this test successfully, it will be necessary to conduct same on a very dark street having only one entrance. It will be necessary to conduct the test before the moon rises, and also extinguish all lights from neighboring farmhouses in order to insure the absence of any possible stray light. Particular care should be taken to avoid a white background of snow. . . . The entire test should be rehearsed the night before until same is carried through to perfection in a real snappy manner. This gives a stage setting which will particularly appeal to the observer."

Thus a consideration of the previous work on the subject indicated that there was a definite need for further research under as close an approximation to actual highway conditions and with as large a number of observers and as wide a range of variables as possible.

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[2] Dickinson and Allen, "Automotive Headlighting Requirements from the Driver's Point of View," *Trans. I. E. S.*, **24**, 1929, p. 15; Dickinson and Allen, "Conclusions from Headlight Research," *Trans. S. A. E.*, **27**, 1932, p. 339.

[3] Harris and Diggs, "Highway Lighting Demonstration," Mimeographed Instructions, G. E. Co., Schenectady, 1932.

2. PROCEDURE.

The tests were performed on highways in the vicinity of Boston, an attempt being made to use a sufficient number of locations with various pavement surfaces, lighted and unlighted, so that the results could be regarded as being fairly representative. Only straight, level portions were used, since it was felt that the introduction of additional factors to the already large number of variables would be confusing without adding anything of importance. Observations were made by six men, each driving his own car. In all cases the observations were made by the driver, with the car in motion on ordinary traveled highways and with the usual traffic.

Each test group consisted of three men: the driver, the pedestrian, and a man who sat beside the driver and recorded the data. The pedestrian was stationed on the pavement near the edge of the road. In making a run the test car proceeded about half a mile beyond the pedestrian, turned around, and started back at a definite speed. When the driver saw the pedestrian he immediately tapped his horn, at which signal the pedestrian stopped walking (if he was in motion) and the data-recorder started his stop watch. The speed was kept accurately at the predetermined value until the car passed the pedestrian, and the data-recorder noted the time elapsing. The visibility distances were computed from these values of time.

In each set of runs constituting a night's work, tests were made at 10, 20, and 40 m.p.h. and with the pedestrian (*A*) in dark clothing, (*B*) with small area of white, and (*C*) with large area of white. In some cases red reflector buttons were used. All these runs were then repeated with an opposing car stationed on the left side of the road and with its headlamps as follows:

Depressed legal beam,
Normal legal beam,
Raised (illegal) beam.

The third condition was obtained by running the front wheels of the car onto 5-inch wood blocks. Such a procedure required less time than the manipulation of the headlamps and also eliminated the possibility of throwing the lamps out of

their normal adjustment. The pedestrian in all these cases was slightly behind the lamps of the opposing car. A final set of measurements was then made at 20 m.p.h. without opposing car, merely as a check on the constancy of conditions. Measurements were also made of the beam candlepower of both cars under operating conditions.

All drivers had previously passed the Massachusetts examination for driver's licenses, but at some time during the research their eyes were again tested. The examination consisted of visual acuity, angle of vision, glare and color tests. In one case vision with glasses was 20/30 (Snellen Test), but in all other respects the eyes of the observers were normal or above normal.

Since speedometer readings were important in the calculation of visibility distance, all speedometers were tested. Headlamps, also, were all carefully adjusted to the same standard.

Tests were made irrespective of weather conditions. It happened that there was no rain during any of the runs, though in a few cases the pavement was wet. Insufficient data were obtained under the latter conditions, however, to allow anything definite to be said as to its effect. Two sets of readings were made during heavy snowstorms, resulting in about 66 per cent. of normal visibility distance.

3. RESULTS.

The principal tests, containing over 5,000 readings made by six observers, are summarized in the Appendix. Each table is similar to the original data sheets used in this series of tests but contains *averages* (also max. and min. values) instead of results obtained in a single run. To make the results more easily comparable, the principal averages are collected in Table I.

Besides the regular tests mentioned above, a number of special runs were made to clarify certain specific questions. We shall first consider all the results obtained on unlighted pavements, reserving for later the effect of lighting from fixed street lamps.

TABLE I.

General Summary of Visibility Distances (ft.), Unlighted and Lighted Pavements.

Pedestrian wearing	*A* Dark Clothes.	*B* Small Area White.	*C* Large Area White.	Average of *A*, *B*, *C*.
I. *With Test Car Only*				
Unlighted Rough Macadam	197	300	387	295
" Smooth "	195	291	377	288
" Concrete	201	320	393	304
Lighted Rough Macadam (*a*)*	200	296	327	274
" Concrete (*b*)	253	288	340	294
" " (*c*)	134	196	241	190
II. Opposing Car with *Legal Normal Beam*				
Unlighted Rough Macadam	166	272	334	257
" Smooth "	139	230	281	217
" Concrete	172	284	348	268
Lighted Rough Macadam (*a*)	159	241	279	226
" Concrete (*b*)	296	318	301	305
" " (*c*)	127	194	225	182
III. Opposing Car with *Legal Depressed Beam*				
Unlighted Rough Macadam	184	292	356	277
" Smooth "	178	285	347	270
" Concrete	192	315	368	292
Lighted Rough Macadam (*a*)	173	288	318	260
" Concrete (*b*)	271	333	342	316
" " (*c*)	134	210	253	199
IV. Opposing Car with *Illegal (raised) Beam*				
Unlighted Rough Macadam	125	225	270	206
" Smooth "	95	164	206	155
" Concrete	147	252	301	233
Lighted Rough Macadam (*a*)	121	197	224	181
" Concrete (*b*)	271	291	289	284
" " (*c*)	98	174	198	157

* Key to lamp spacing and rating.

(*a*) Three locations averaged { Spacing 265′—Rating 800 Lumens. " 500′— " 800 " " 250′— " 600 "

(*b*) One location only " 150′— " 6,000 "

(*c*) Two locations averaged { " 700′— " 800 " " 525′— " 800 "

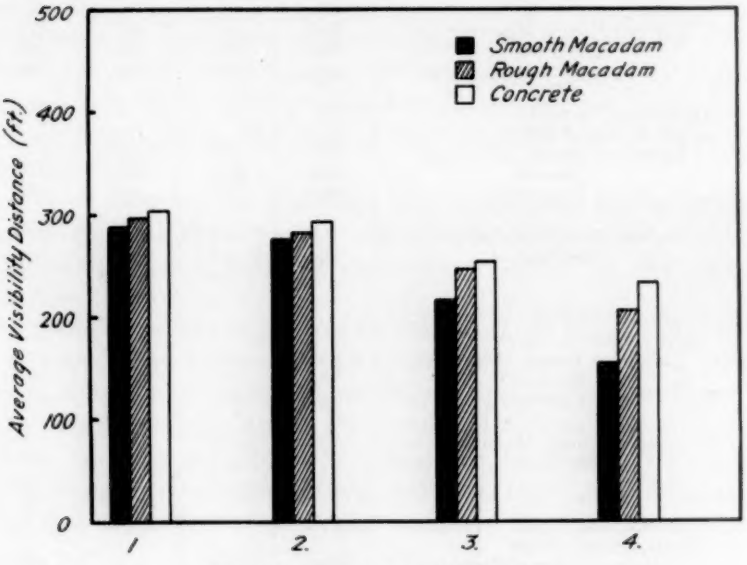
Note: Pedestrian located midway between street lights.
Values are averages for all test speeds.

UNLIGHTED PAVEMENTS.

Effect of Pavement.

One of the many variables which affect visibility distance is the type of pavement. The results are summarized in Fig. 1. It will be noted that with unlighted pavements and

FIG. 1.



Effect of pavement surface (unlighted).
1. No glare.
2. Opposing car with depressed beam.
3. Opposing car with normal driving beam.
4. Opposing car with illegal (raised) beam.

no glare from opposing cars, the average visibility distances are 288, 295, and 304 ft. for smooth macadam, rough macadam, and concrete pavements respectively. The improvement due to the use of concrete was expected. Low values are obtained throughout with smooth macadam which may be due to the specular component of reflection. Similar results are obtained when glare is present. The conclusions are, therefore, that

(1) Pavement surfaces rated in order of their visibility distance are:

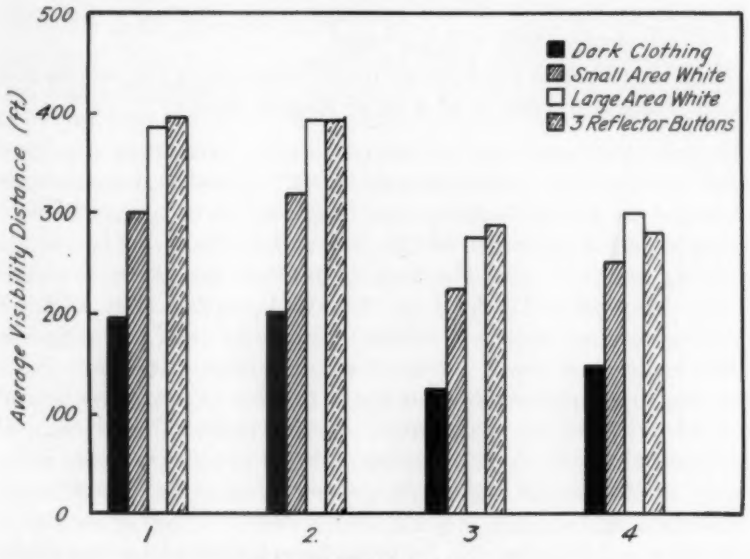
Concrete (best),
Rough macadam (intermediate),
Smooth macadam (worst).

(2) The difference is hardly perceptible with no glare, but becomes more and more marked as glare increases. Except in the case of an opposing car with extremely glaring lights, however, the effect of type of pavement is small and can in most cases be neglected.

Effect of Pedestrian's Clothing.

Figure 2 summarizes the effect of the pedestrian's clothing

FIG. 2.



Effect of pedestrian's clothing.
1. No glare, rough macadam pavement.
2. No glare, concrete pavement.
3. Opposing care with glaring headlamps, rough macadam pavement.
4. Opposing car with glaring headlamps, concrete pavements.

on the visibility distance. It will be noted that with an unlighted rough macadam pavement and no opposing car the average visibility distance is 197 ft. for a pedestrian in dark clothes. If, however, the pedestrian exposes a small area of white, such as an unfolded handkerchief, the visibility distance

increases by 50 per cent., or to 300 ft. With a white area of 3 or 4 sq. ft., such as a white apron, white dress, etc., the distance is increased to 387 ft., approximately double its initial value. Three red reflector buttons gave a value of 396 ft. with dark clothing.

The effect of clothing for several other representative conditions of unlighted pavements is likewise shown in Fig. 2. In these, as in all other tests, the conclusions are:

(1) A pedestrian in dark clothing is in grave danger, irrespective of type of pavement surface or other factors.
(2) A small area of white increases the visibility distance approximately 50 per cent. (Somewhat more than 50 per cent. in the case of glaring lights.)
(3) A large area of white increases the visibility distance approximately 100 per cent.
(4) Three reflector buttons with dark clothing give practically the same results as a large area of white.

The reflector buttons [4] employed in our tests were the kind used in reflecting-type highway signs. They had an outside diameter of approximately one inch and were arranged in a triangle which was worn at the pedestrian's belt. The results of using one, two and three such buttons are given in detail in the Appendix, Table *A*-4. It will be noted that with all pavements and with or without opposing car, the reflector buttons gave a great increase in visibility distance. Such buttons are inexpensive and their use by pedestrians would undoubtedly reduce accidents. In this connection, it should be noted that the type of reflector button is important, since many kinds do not have the property of reflecting a beam for sufficient distance. A flat red reflector about 2 inches in diameter, sold for use on bicycles, was found to be worthless for our purpose.

Effect of Speed.

Previous tests by others [5] had indicated no effect of speed on visibility distance. In the present tests, nevertheless, it was thought advisable to take runs at various speeds if for

[4] See also F. W. Mills, "The Comparative Visibility of Standard Luminous and Non-luminous Highway Signs," *Public Roads*, 14, 1933, p. 109.

[5] Dickinson and Allen, *loc. cit.*

no other reason than to provide additional variety for the test crews and to give a rough check for errors due to reaction time and speedometer readings. Tables *A*-1 to *A*-3 of the Appendix show that speed has a small or negligible effect. It is true that values of visibility distance at 20 m.p.h. are consistently slightly higher than at either 10 or 40 m.p.h., but the differences are so small that it is permissible to average results at all speeds, as has been done in many of the tables.

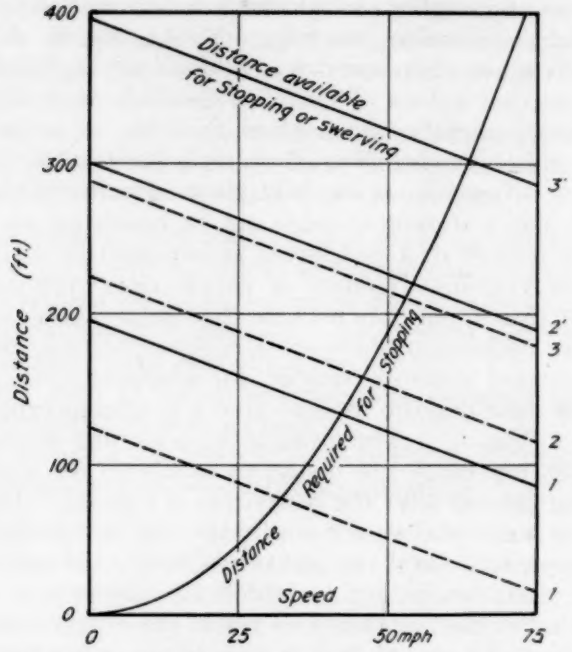
The above statement must not be construed as meaning that the danger to a pedestrian is independent of the speed of motor vehicles. Danger of course rises very rapidly as speed increases, not only because the time available for action by either pedestrian or driver is reduced but also because of the increased distance needed for stopping the car. The previous data may be used to give a graphical expression of this fact (Fig. 3). The straight lines sloping downward to the right represent the distances available for stopping or swerving the car after the pedestrian is sighted. These lines would be horizontal were it not for the fact that an appreciable time elapses between the instant at which the pedestrian is sighted and the instant at which the driver can begin to apply the brakes. Exhaustive tests [6] show that this interval varies from 0.5 sec. to over 1.0 sec., even when the surprise element is almost entirely lacking. In calculating the curves of Fig. 3 we have arbitrarily taken a one-second time lag as being a representative value for ordinary operating conditions, though a quick operator, keenly awake and thoroughly on the job, might have curves of lesser slope.

The other curve, sloping upward to the right, represents the distance required for stopping an average car equipped with four-wheel brakes.[7] Evidently speeds to the left of the intersection of the latter curve with the straight lines are safe speeds which (for dry pavements, good brakes, etc.) will allow the stopping of the car before the pedestrian is reached. Intersections with 1 and 1′ are of particular interest because they show that with pedestrians in dark clothes, maximum safe speeds at night are approximately 30 m.p.h. when glare

[6] Report of Massachusetts Highway Accident Survey, 1934.

[7] "Legislation Relating to Motor Vehicles," Commonwealth of Mass. Pub. No. 9681, Oct. 1933, p. 172.

FIG. 3.



Approximate maximum safe speeds on unlighted pavements. 32 c.p. bulbs, legal driving beam, one sec. time lag of driver.

1. Pedestrian with dark clothing. Glare.
1'. Pedestrian with dark clothing. No glare.
2. Pedestrian with small area white. Glare.
2'. Pedestrian with small area white. No glare.
3. Pedestrian with 3 reflector buttons. Glare.
3'. Pedestrian with 3 reflector buttons. No glare.

is present and 40 m.p.h. without glare. The great improvement in pedestrian safety insured by the use of reflector buttons (or by the use of light-colored clothes) is shown by the intersections near the top of the figure. The data used in Fig. 3 are for rough macadam pavements, but the same general conclusions may be drawn for concrete.

It should be emphasized that the safe speeds obtainable from Fig. 3 are to be regarded as optimum values, even though a fairly large time lag has been assumed for the driver. A decrease in time lag to 0.5 sec. increases the maximum safe speed less than 5 m.p.h.; but wet or icy pavements, poor brakes, a wet or dusty windshield, or an inattentive driver may reduce safe speed almost to zero.

Effect of Glare.

As a part of the regular tests, measurements were made of illumination from all headlamps under actual operating conditions. In the case of the opposing cars, illumination measurements were made on a vertical plane 50 ft. in front of the headlamps, 4 ft. to the right of the center-line of car (facing the lamps), and 4 ft. above the pavement. The candlepower in this direction is an approximate measure of glare. Illumination readings were translated to glare c.p. by multiplying by the square of the distance.

The results obtained in the case of unlighted rough macadam pavement are given in Table II and plotted in Fig. 4,

TABLE II.
Effect of Glare.

	Av. Glare Illum.	Av. Glare c.p.	Visibility Distance.			Fraction of Original Visibility Distance.			
			A.	*B.*	*C.*	*A.*	*B.*	*C.*	Av.
No opposing car.....	0	0	197	300	387	1.00	1.00	1.00	1.00
Depressed beam.....	0.20	490	184	292	356	0.938	0.970	0.918	0.942
Normal beam.....	0.34	860	166	272	334	0.847	0.904	0.861	0.871
Illegal beam.....	1.69	4230	125	225	270	0.638	0.747	0.696	0.694

Note: Data are for unlighted rough macadam pavements. *A*, *B* and *C* refer, as usual, to pedestrian in dark clothes, with small area white, and with large area white, respectively. Values are taken from Appendix, Table *A*-1.

where the four points of each curve represent average glare c.p. of opposing car with lights off, depressed beam, normal beam, and illegal beam. It will be noted that the visibility distance is decreased as the glare increases, the reduction in the worst case of illegal lights being about 40 per cent. Similar results were obtained on smooth macadam and on concrete pavements, also on lighted pavements. The results of Table II may be represented by an empirical equation of the form:

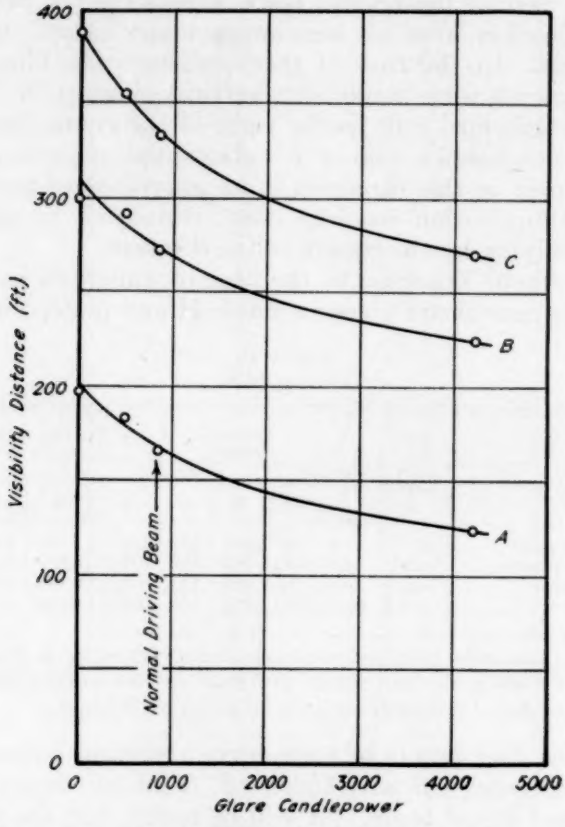
$$p = (10)^{-ax}. \qquad (1)$$

p = av. visibility distance expressed as a fraction of visibility distance with no opposing car,

a = 0.0322,

x = glare c.p. expressed as a fraction of glare c.p. from normal driving beam.

FIG. 4.



Visibility distance as a function of glare. Unlighted rough macadam pavements.
A—Pedestrian with dark clothes.
B—Pedestrian with small area white.
C—Pedestrian with large area white.

Effect of Headlamp Candlepower.

Since both 32 and 21 c.p. bulbs are used extensively in headlamps, and since bulbs are often operated on reduced voltage, the question of the effect of headlamp c.p. is of interest. A separate set of tests was therefore made to determine the effect of c.p. over a wide range. 32 c.p. bulbs were used and a rheostat and ammeter were introduced into the circuit so that the lamp current could be kept at any pre-

determined value. The percentage of normal c.p. was then computed using the formula:

$$\frac{I}{I_0} = \left(\frac{i}{i_0}\right)^{6.24}, \qquad (2)$$

where i_0 = normal current (no resistance),
i = current with resistance inserted,
I_0 = c.p. corresponding to i_0,
I = c.p. corresponding to i,

and the value 6.24 was obtained from tests made on similar bulbs by the Bureau of Standards.[8]

The results on unlighted rough macadam pavements are given in Table III and Fig. 5. It will be noted that fairly

TABLE III.
Effect of Headlamp Candlepower.

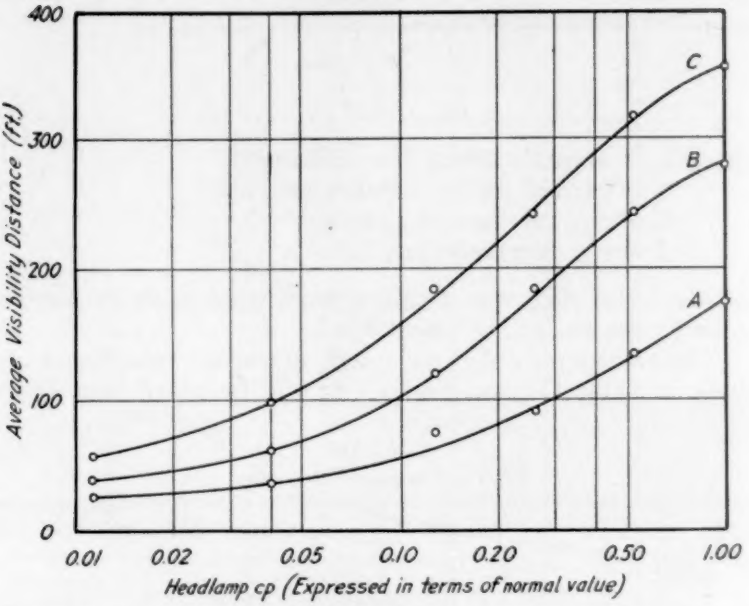
Per Cent. Normal Current.	Per Cent. Normal c.p.	Av. Visibility Distance (ft.)		
		A. Dark Clothes.	*B.* Small Area White.	*C.* Large Area White.
100	100	175	281	355
90.3	52.5	135	243	317
80.5	26.1	91	184	243
72.0	12.8	75	120	184
59.8	4.1	36	61	99
48.8	1.1	26	39	57

Note: Unlighted rough macadam pavement. No opposing car. 32 cp. bulbs operated with resistance dimmer, zero resistance in first test. Data are the averages of six runs at 20 m.p.h. made by two observers.

smooth curves are obtained showing a rapid increase in visibility distance as the c.p. is raised. The curve for dark clothing indicates a 14 per cent. decrease in visibility distance for a decrease in c.p. equal to the replacement of 32 c.p. bulbs by 21 c.p. Evidently the use of still smaller bulbs or their operation at reduced voltage is not to be recommended. Similar curves were obtained for unlighted concrete pavements.

[8] Barbrow and Meyer, "Characteristic Equations of Vacuum and Gas-filled Tungsten Filament Lamps," *Bu. Stds. J. R.*, 9, 1932, p. 721.

FIG. 5.



Visibility distance as a function of headlamp candlepower. Unlight rough macadam pavements, 32 candlepower headlamp bulbs. *A*, *B* and *C* refer to pedestrian's clothing.

The points of curve *A*, Fig. 5, are well represented by the equation:

$$\text{Visibility distance} = 178x^{0.454}, \qquad (3)$$

where x = headlamp c.p. expressed in terms of normal value (with 32 c.p. bulbs)

Thus for the conditions of rough macadam pavements, no glare, and pedestrian in dark clothing, the visibility distance is given by eq. (3). Visibility distance when glare is present should then be obtainable by multiplying the right side of (3) by p. If the headlamps of the opposing car are the same as those of the test car, both adjusted for the normal driving beam,

$$\text{Visibility distance} = 178\ (10)^{-0.0322x}x^{0.454}. \qquad (4)$$

It is interesting to consider what information eq. (4) can give in regard to the best size of headlamp bulbs, assuming that

this size bulb is used on all cars. Evidently the use of bulbs of very low c.p. is inadvisable because, though glare from passing cars becomes negligible, the beam is too weak to be of any use. On the other hand, one might expect that very powerful headlamps would result in such annoying glare that large visibility distances would be impossible. Indeed, eq. (4) exhibits a peak at 195 bulb c.p., at which value the visibility distance is 258 ft. (with glare). While it is true that the extrapolation of the Fig. 5 curve to such an extent is questionable, it is certain that the increase in bulb c.p. somewhat above 32 would increase visibility distance in the case of pedestrians in dark clothing. Table IV gives some results

TABLE IV.

Calculated Effect of Changing Headlamp Bulb C.P. of Both Cars.

Headlamp Bulb c.p.	x.	p.	Visibil ty Distance (ft.).	
			No Glare.	With Glare.
6	0.187	0.98	84	83
15	0.469	0.96	126	122
21	0.666	0.95	148	141
32	1.00	0.93	178	165
50	1.56	0.90	216	194
100	3.12	0.79	298	236

Note: Above values calculated from equations (3) and (4), assuming both test car and opposing car have the same headlamps and both are using the normal legal beam. Data are for unlighted rough macadam pavements with pedestrian in dark clothes.

calculated by eq. (4), showing the beneficial results of increasing headlamp c.p.

A similar conclusion seems possible in regard to depressing or dimming the beam when passing another car. Although depressing the beam allows better visibility of the road shoulder, it practically eliminates any possibility of seeing a pedestrian, the latter being visible only when a strong normal beam is used. In this connection, the new cross-beam type of headlamp [9] appears to be an improvement. Several tests on such headlamps gave a distinct, though not phenomenal, increase in visibility distance.

[9] Brown and Roper, "Limiting Factors in Design of Motor Vehicle Headlamps," *Trans. I. E. S.*, 29, 1934, p. 175.

ILLUMINATED HIGHWAYS.

Results of tests made on a number of illuminated highways are summarized in Table V which gives an indication of the

TABLE V.

Comparison of Visibility Distances for Lighted and Unlighted Pavements.

Pedestrian Wearing	Average Visibility Distance (ft.).			
	A. Dark Clothes.	*B*. Small Area White.	*C*. Large Area White.	Average of *A*, *B*, and *C*.
Rough Macadam				
1. Unlighted	197	300	387	295
2. Incandescent Lamps	200	296	327	274
3. Incandescent Lamps, I. E. S. Code	234	302	320	285
Concrete				
4. Unlighted	201	320	393	304
5. Incandescent Lamps	134	196	241	190
6. Parkway Standards	253	288	340	294
7. Worcester Tpk., Incandescent Lamps	727	698	786	737
8. Worcester Tpk., Sodium-Vapor Lamps	1283	1159	1272	1238

Description of Lighting Systems.

Item No.	Pavement.	Type.	Spacing of Units.	Rating (Lumens).	Height.	Brackets.
2	20 ft. R.M.	Incandescent	265′ one side	800	14′	4′
		"	500′ " "	800	14′	4′
		"	250′ " "	600	14′	4′
3	40 ft. R.M.	"	250′ staggered	4,000	25′	14′ and 9′ alt. each side
5	40 ft. Concrete	"	700′ one side	800	14′	4′
	30 ft. "	"	525′ " "	800	14′	4′
6	40 ft. Concrete	"	150′ staggered	6,000	14′	None
7	2–30 ft. Roadways separated by 10 ft. grass plot.	"	150′ "	6,000	22′	8′
8	2–30 ft. Roadways separated by 10 ft. grass plot.	Sodium	150′ "	10,000	22′	8′

Note: No opposing car. Pedestrian midway between lights on lighted locations.

Values are averages for all speeds.

change in visibility distance caused by the illumination of the pavement by fixed street lamps. For simplicity, Table V gives only tests made with no glare from an opposing car, but results with glare are similar. The test car was operated with the normal legal headlamp beam and the pedestrian was midway between street lamps and against the usual dark background.

Item (1) gives the results for unlighted rough macadam pavements, while (2) gives the average of results obtained on three locations having very small lamps and large spacings. Such designs are, of course, very poor examples of street lighting and would not be installed today on any important highway. The average visibility distance is seen to be practically the same as without street illumination. Item (3) gives the results obtained on a four-lane highway which has been lighted recently according to the specifications of the I. E. S. Code of Street Lighting.[10] Average visibility distances are seen to be nearly the same as with no lamps.

On concrete pavements, (5) gives the average of two locations with 800 lumen lamps and large spacing. Such installations give very little illumination, yet the lamps are a source of glare. The result is a distinct decrease in visibility distance. Items (7) and (8) give results obtained on the Boston-Worcester Turnpike in Newton, where a portion of the pavement is lighted by incandescent lamps and an adjacent section by sodium-vapor lamps. The tremendous increase in visibility distance is apparent. The difference between (7) and (8) is probably due largely to the greater illumination in the latter case, though the monochromatic nature of the radiation from the sodium-vapor lamps may also be important. Location (6) bears a superficial similarity to (7). It is an older installation, however, using parkway units set at some distance from the curb and with a mounting height of only 14 ft., while (7) is modern design with lamps mounted at greater height and suspended over the pavement. As might be expected, the results on (6) are unsatisfactory.

Because of the recent interest in highway lighting as a panacea for all ills, the results obtained on location (3) are of particular interest. This installation was carefully designed

[10] *Trans. I. E. S.*, 26, 1931, p. 15.

on the basis of modern ideas of highway lighting and in accordance with the minimum specifications of the I. E. S. Code. The test results show a 19 per cent. increase in visibility distance for the pedestrian in dark clothes, but the average visibility distance is slightly lower than that obtained on similar locations with no lighting. It is likely that such an installation would have been satisfactory had the pavement been of concrete, but for rough macadam pavement the I. E. S. specifications are evidently inadequate.

The effect of highway illumination can be visualized from Fig. 6. The visibility distances are taken from Table V, while the values of average pavement luminosity [11] are based on the measurements of Medrano [12] and on the assumption of 4 per cent. reflection factor for rough macadam and 50 per cent. average reflection factor for concrete. The points are seen to be fairly consistent excepting (6) for the parkway standards, which can be disregarded on the basis of modern practice. It is realized, of course, that a single factor such as average pavement luminosity is but the roughest kind of a criterion of street lighting. The most important factors influencing visibility distance are probably luminosity of pedestrian, contrast between pedestrian and his background, and glare illumination at the driver's eyes. The average pavement luminosity, however, appears to be as satisfactory as any single measure of street lighting.

The general conclusion is, therefore, that pavement illumination from fixed street lamps has little or no effect on visibility distance unless the luminosity of the pavement is fairly high. In fact, the data indicate that unless the pavement luminosity is at least 0.05 lumen/ft.^{2} the glare from the street lamps tends to overbalance any good effect of the

---

[11] The term *luminosity* refers to the total luminous flux reflected by the pavement per sq. ft. of surface. For all surfaces, perfectly-diffusing or otherwise, it is determined from the illumination by the simple relation:

$$L = \rho E,$$

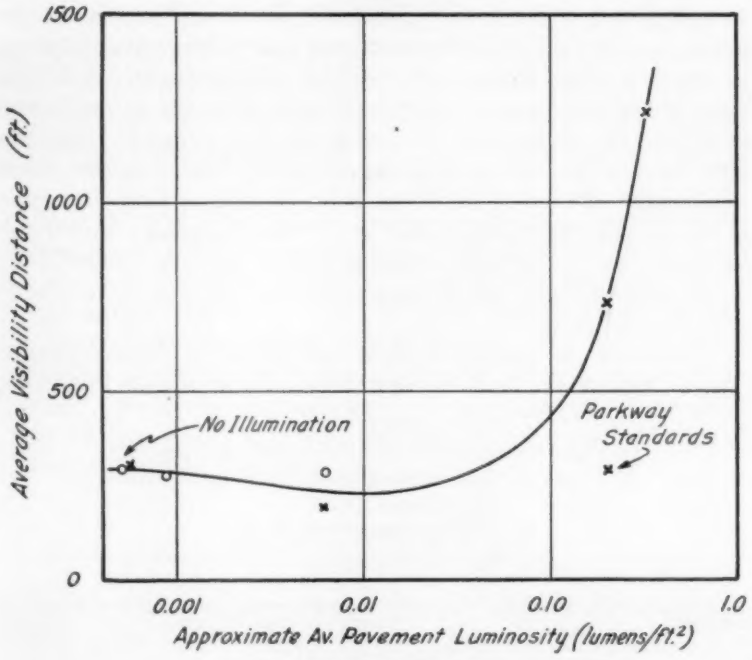
where

L = luminosity (lumens/ft.^{2}),
ρ = reflection factor,
E = illumination (lumens/ft.^{2}).

[12] J. C. Medrano, "A Study of Street Lighting," M. I. T., E.E. Thesis, 1932.

added illumination.[13] As the pavement luminosity is increased beyond about 0.1 lumen/ft.^{2}, however, the visibility distance is greatly improved. It is interesting to note that these transition values are in approximate agreement with the luminosity at which the cones of the retina of the human eye begin to function. Troland[14] gives a value of 0.05 lumen/ft.^{2} for this *chromatic threshold*. The classic researches of König on visual acuity[15] give a curve not unlike that shown in Fig. 6. The acuity increases slowly (scotopic vision) as luminosity increases until the cones begin to function, beyond

FIG. 6.



Effect of highway illumination.
o—Rough macadam pavements.
x—Concrete pavements.

[13] Such a value of average luminosity is obtained approximately on a 35-ft. concrete pavement by the use of 4,000-lumen lamps on 250-ft. centers.

[14] L. T. Troland, *Trans. I. E. S.*, **26**, 1931, p. 165.

[15] A. König, "Die Abhängigkeit der Sehschärfe von der Beleuchtungsintensität," *Sitz. Berlin Akad. Wiss.*, **13**, 1897, p. 559.

which the curve rises very rapidly (photopic vision). Apparently, then, the great increase in visibility distance shown in the right-hand part of Fig. 6 is due to a change from scotopic to photopic vision; and excellent results may be obtained if the illumination from street lamps is sufficient to allow photopic vision.

It must be realized, of course, that these conclusions apply only to the conditions under which the tests were made. The pedestrian was mid-way between lamps and the background was fairly dark. If the pedestrian can be distinguished by silhouette against a white fence or other object, street lighting may greatly increase visibility distance even though illumination is very low. In Table V, Location 3, for instance, the visibility distance was found to increase to 650 ft. when a white fence was used as background. It is also true that positions can often be found near the street lamps at which the pedestrian is visible at 500–1,000 ft. Several runs (not included in this paper) were made under these conditions. It was considered a fairer comparison, however, to use the data obtained with the pedestrian in an unfavorable position, since *if highway lighting is to be effective it must reveal the pedestrian under all circumstances and not merely in certain favorable positions.*

Statistics on motor vehicle accidents in Massachusetts (Table VI) seem to corroborate our conclusion regarding

TABLE VI.

Summary of Fatal Automobile Accidents in Massachusetts.

Data from the Office of the Registrar of Motor Vehicles, Boston, Mass.

Total Fatal Accidents.

	1930.	1931.	1932.	1933.	Total.
Daylight	364	374	320	308	1366
Dark (including dusk and dawn)	391	375	403	419	1588
Totals	755	749	723	727	2954

Night Accidents Classified with Respect to Street Lighting.

Unlighted	64	50	59	73	246
Poor street lighting	101	88	120	96	405
Good " "	174	178	163	161	676
Excellent "	25	22	23	45	115

street lighting. The astonishing thing about these results is the great preponderance of fatal accidents occurring with lighting classified by the inspectors as "good." Few accidents occur on unlighted roads and very few where the lighting is "excellent." It is true that these figures, in common with all statistics, suffer from the difficulty of evaluating the numerous contributory factors. Is the lowness of the value obtained with excellent lighting, for instance, caused by the lighting, or is it due to the small number of streets so lighted, or is it because highly-illuminated pavements are generally found only in the principal business sections of large cities where speeds are necessarily so low that accidents seldom result in fatalities? Notwithstanding such uncertainty, the great number of fatal accidents occurring with ordinary street lighting compared with the small number with no lighting certainly does not point to the effectiveness of ordinary street lighting.

4. ACCURACY OF THE RESULTS.

In analysing the results, it is interesting to consider what significance, if any, attaches to a difference of a few feet in an average visibility distance. For rough macadam pavements and pedestrian in dark clothes, for instance, does the difference between 192 ft. obtained at 10 m.p.h. and 202 ft. obtained at 20 m.p.h. mean anything, or is it merely accidental? In order to answer such questions, we analysed some of the data, obtaining the probable error of a single observation from the formula:

$$\text{P.E.} = 0.6745\sqrt{\frac{\Sigma(\delta)^2}{n}},$$

where δ is the deviation from the mean and n is the number of observations. Each figure of Table VII represents an analysis of from 30 to 90 observations. For the pedestrian in dark clothes and a speed of 40 m.p.h., for example, the probable error of a single observation of $\pm$ 51.1 ft. This means that if we select at random one of the observers who made the test and let him take a single observation on any of the unlighted rough-macadam pavements used in the tests, he has a 50 : 50 chance of getting within $\pm$ 51 ft. of the average

TABLE VII.

Probable Error.

Probable Error of a Single Observation (ft.).

Speed.	*A.* Dark Clothes.	*B.* Small Area White.	*C.* Large Area White.
10 m.p.h.	38.0	70.0	86.1
20 m.p.h.	41.1	77.4	96.6
40 m.p.h.	51.1	79.2	101.5

Probable Error of a Single Observation Expressed in Per Cent. of Av. Visibility Distance.

10 m.p.h.	19.8	23.9	22.7
20 m.p.h.	20.4	24.8	24.3
40 m.p.h.	26.1	26.9	26.5

Values obtained by analysis of data for unlighted rough macadam pavements with no opposing car.

value (197 ft.) obtained under these conditions. This is a rather large probable error, due presumably to the number of variables which were only imperfectly under control and particularly to the variable human element. The lower part of Table VII gives the same data expressed in terms of the average visibility distances instead of in ft. In this way the variation due to the change in average visibility distance is eliminated, resulting in a probable error which is essentially the same for all conditions.

A more important result can be obtained from Table VII by use of the fact that the probable error of an average of N observations varies inversely as the square root of N. For 20 m.p.h., dark clothes, and an average of 47 observations, the probable error of the average is

$$\pm \frac{41.1}{\sqrt{47}} = \pm 6.0 \text{ ft.}$$

Thus the average visibility distance under these conditions may be written as 202 ± 6.0 ft. The actual differences between values at 10 and at 40 m.p.h. are, however, 10 ft. and 6 ft. respectively. The conclusion is that probably the variation is a random one. On the other hand, with averages such as 201 ft. for unlighted concrete and 134 ft. for lighted con-

crete pavements, one can say positively that the difference is not caused by random errors.

The above errors are, of course, *random errors* and give no indication of the absolute accuracy of the results. Certain *fixed errors* are also present. The results are so greatly influenced by the personal element as well as by external conditions (flux distribution from the headlamps, effect of moonlight, shading of road by trees, snow on pavement or road shoulder, etc.) that it is doubtful if our averages could in general be reproduced closer than 30 or 40 ft. by other groups in different locations.

Because of the inherent meaninglessness of exact statements of absolute visibility distance, it was obviously unnecessary to determine the values of variables with high precision. In the measurement of glare c.p., for instance, a 50-ft. distance was used for convenience though probably a 100-ft. distance would have given somewhat more accurate values. Equation (2) for the variation of c.p. with current is also admittedly an approximation at the lowest values of current used, yet the errors so caused are small compared with the errors due to the human element.

One factor, which was investigated in some detail with respect to its effect as a constant error, was the reaction time of observer and recorder. Visibility distance, by definition, is the distance from driver to pedestrian at the instant of sighting the latter. All the recorded values, however, are distances covered by the car while the stop watch is in operation. An attempt was made to determine the difference between these two distances (or the corresponding times). Tests were run with exactly the ordinary procedure except that a positive stimulus was given by the sudden operation of a small neon lamp near the stationary pedestrian. The true elapsed times were accurately measured by an electric device developed by Messrs. Davis and Ross in their general study of reaction time. The times obtained with the watch were less than the true values, the average differences being 0.49 sec. It seems likely that this represents the sum of the reaction time of the driver and the reaction time of the recorder in starting the watch and that the error in stopping the watch tends to be indiscriminately plus or minus.

Though the above tests simulated the visibility tests as nearly as possible, there was an unavoidable difference between the sharply-defined flash of the lamp and the indefinite appearance of a dimly-lighted pedestrian. Conditions were further complicated in the visibility test by the division of the driver's attention caused by traffic and by the necessity of keeping the car at constant speed. This factor did not seem to alter results when the definite stimulus was used but had a distinct effect in the ordinary runs, as shown by the results of another set of tests (Table VIII). All readings

TABLE VIII.

Visibility Distance as Obtained by Driver and by Same Man as Passenger.

Pedestrian Wearing—	Visibility Distance (ft.).								
	A. Dark Clothes.		*B*. Small Area White.		*C*. Large Area White.		Average of *A*, *B* and *C*.		Ratio:
	Driver.*	Passenger.†	Driver.	Passenger.	Driver.	Passenger.	Driver.	Passenger.	Driver, Passenger.
Observer									
No. 1..	153	238	282	490	323	555	253	428	0.59
No. 2..	171	191	270	353	353	488	265	344	0.77
No. 3..	259	223	352	485	482	520	364	409	0.89
No. 4..	305	317	400	432	441	532	382	427	0.89
No. 5..	289	333	408	521	612	684	436	513	0.85
No. 6..	229	194	306	379	520	528	351	367	0.95
Average	234	249	336	443	455	551	342	414	0.82

Note: Above figures are result of special test on unlighted rough macadam pavement, no opposing car, each figure the average of three (3) runs.

* Observer driving his own car.

† Car being operated by another driver.

in the latter investigation were taken with the same conditions, the columns marked *driver* being obtained in the usual manner while those marked *passenger* were obtained with the same men riding in the front seat as passengers. It will be noted that in nearly every case the readings are higher when the observer is not driving the car, a conclusion which might be expected from the fact that under such conditions he can concentrate his entire attention upon detecting the pedestrian.

In the actual visibility tests, we have found a propensity

on the part of the driver to slightly anticipate, thereby tending to cancel the reaction time. Because of this and because of the complicating effect indicated by Table VIII, we did not attempt to correct visibility distances for reaction time. All the tabulated distances, therefore, are measured values. On the whole, it seems likely that the visibility distances given in the present paper are somewhat *higher* than those which would be obtained by the average driver under average conditions in practice since the surprise element was lacking in our tests. This does not affect the general conclusions but merely indicates that our numerical results are to be considered as obtainable under the best conditions: thoroughly wide-awake drivers with good vision operating under good weather conditions.

5. CONCLUSIONS.

Conclusions from the Pedestrian's Standpoint.

1. Pavements rated in order of visibility distance are

a. Concrete,
b. Rough macadam,
c. Smooth macadam.

The differences are small, however, so a pedestrian is in approximately as much danger on one kind of pavement as on another.

2. A small area of white, such as an unfolded handkerchief, increases the visibility distance approximately 50 per cent.; while light-colored clothing or the use of three or more reflector buttons of the correct type increases the visibility distance 100 per cent. Figure 3 shows that at speeds above 40 m.p.h., a driver cannot see a pedestrian in dark clothes soon enough to stop before reaching him. If, however, reflector buttons are used, a driver going at 60 m.p.h. can stop in time. In the case of glare from passing cars, these values are reduced to 30 m.p.h. and 50 m.p.h., respectively. Keeping in mind that even these speeds are unsafe in the case of unfavorable weather, poorly-adjusted brakes, sub-normal eyes, or inattention on the part of the driver and considering the high speeds frequently used, one cannot help being impressed by the danger to the pedestrian—a danger which is

amply demonstrated by the number of fatal accidents which occur.

Conclusions from the Motorist's Standpoint.

1. Fig. 3 shows that with 32 c.p. bulbs, a speed above 30 m.p.h. is unsafe when passing cars with glaring lights; and speeds above 40 m.p.h. are unsafe when there is no glare. Of course, at higher speeds there may still be time to swerve sufficiently to miss the pedestrian even though there is insufficient time to stop the car; but this certainly cannot be regarded as safe practice. On the contrary, a factor of safety should be introduced to take care of poor brakes, wet pavement, wet or dusty windshield, a tired driver, etc.

2. Table IV indicates that 32 c.p. bulbs should be used in preference to 21 c.p. Indeed, the legalization of still larger lamps would seem advisable since the added glare is (for a wide range of c.p.) more than compensated by the increased visibility.

3. The test indicated that, insofar as visibility distance is concerned, depressing or dimming the beam is inadvisable.

Conclusions in Regard to Highway Lighting.

Three methods of increasing visibility distance are:

(*a*) Use of reflector buttons on pedestrians,
(*b*) Increase in beam c.p. of headlamps,
(*c*) Highway lighting.

In regard to (*c*), the tests indicate that with present types of incandescent street lamps and with the pedestrian in an unfavorable position between lamps no appreciable gain in visibility distance is to be expected from highway lighting unless the average luminosity of the pavement is of the order of 0.05 lumen/ft.^{2} or better. With lower values of luminosity, glare from the street lamps appears to offset the advantages of increased illumination. Such a conclusion seems to be substantiated by the records of fatal automobile accidents in Massachusetts.

In conclusion, the writers wish to express their appreciation of the support and helpful suggestions of Col. R. C. Eddy, Dr. V. Bush, and Mr. Allen. Thanks are also due to the men who carried out the actual experimental work, for their unflagging zeal and interest.

TABLE A-1.
Summary of Tests on Unlighted Rough Macadam Pavements.

TABLE *A*-1.

Summary of Tests on Unlighted Rough Macadam Pavements.

Pedestrian Wearing	Visibility Distance (ft.).									
	A. Dark Clothes.			*B*. Small Area White.			*C*. Large Area White.			Average of *A*, *B* and *C*.
	Min.	Av.	Max.	Min.	Av.	Max.	Min.	Av.	Max.	
I. *With Test Car Only*										
10 m.p.h.	106	192	353	118	293	495	165	379	608	288
20 m.p.h.	111	202	343	115	312	530	153	398	694	304
40 m.p.h.	101	196	470	101	294	574	135	383	751	291
Average		197			300			387		295
II. Opposing Car with *Legal Normal Beam*										
10 m.p.h.	71	161	281	91	268	476	135	327	570	252
20 m.p.h.	70	170	364	76	273	496	132	341	640	261
40 m.p.h.	47	167	366	94	274	470	135	334	647	258
Average		166			272			334		257
III. Opposing Car with *Legal Depressed Beam*										
20 m.p.h.	88	184	364	114	292	550	100	356	670	277
IV. Opposing Car with *Illegal (raised) Beam*										
10 m.p.h.	53	124	248	32	219	457	26	260	542	201
20 m.p.h.	29	131	346	35	229	517	53	268	517	209
40 m.p.h.	11	120	345	82	227	438	82	281	540	208
Average		125			225			270		206
V. *With Test Car Only* (Check Run)										
20 m.p.h.	118	202	327	114	311	575	134	394	772	302

Note: Each figure given above is the average of 47 values. Data were taken by 6 observers.

TABLE *A*-2.
Summary of Tests on Unlighted Smooth Macadam Pavements.

Pedestrian Wearing	Visibility Distance (ft.).									
	A. Dark Clothes.			*B*. Small Area White.			*C*. Large Area White.			Average of *A*, *B* and *C*.
	Min.	Av.	Max.	Min.	Av.	Max.	Min.	Av.	Max.	
I. *With Test Car Only*										
10 m.p.h.	97	198	291	125	296	686	176	384	715	293
20 m.p.h.	94	206	377	114	314	635	134	397	700	306
40 m.p.h.	84	182	293	118	262	422	186	350	600	265
Average		195			291			377		288
II. Opposing Car with *Legal Normal Beam*										
10 m.p.h.	67	140	235	100	239	536	126	286	603	222
20 m.p.h.	59	154	380	88	248	534	135	295	632	232
40 m.p.h.	70	124	188	81	203	352	94	262	481	196
Average		139			230			281		217
III. Opposing Car with *Legal Depressed Beam*										
20 m.p.h.	82	178	297	130	285	584	176	347	539	270
IV. Opposing Car with *Illegal (raised) Beam*										
10 m.p.h.	44	102	337	32	176	470	79	216	496	165
20 m.p.h.	29	110	344	41	180	449	70	234	533	175
40 m.p.h.	12	72	153	12	136	282	82	169	317	126
Average		95			164			206		155
V. *With Test Car Only* (Check Run)										
20 m.p.h.	100	237	700	141	316	635	206	401	690	318

Note: Each figure given above is average of 27 tests made by 6 observers.

TABLE *A*-3.
Summary of Tests on Unlighted Concrete Pavements.

TABLE *A*-3.

Summary of Tests on Unlighted Concrete Pavements.

Pedestrian Wearing	Visibility Distance (ft.).									
	A. Dark Clothes.			*B*. Small Area White.			*C*. Large Area White.			Average of *A*, *B* and *C*.
	Min.	Av.	Max.	Min.	Av.	Max.	Min.	Av.	Max.	
I. *With Test Car Only*										
10 m.p.h.	109	203	370	147	311	536	179	384	649	299
20 m.p.h.	106	205	385	124	333	609	191	399	650	312
40 m.p.h.	94	194	385	148	316	518	169	396	645	302
Average		201			320			393		305
II. Opposing Car with *Legal Normal Beam*										
10 m.p.h.	88	173	316	118	280	603	150	345	652	266
20 m.p.h.	94	179	282	111	297	621	147	357	638	278
40 m.p.h.	81	164	282	84	275	483	188	341	540	260
Average		172			284			348		268
III. Opposing Car with *Legal Depressed Beam*										
20 m.p.h.	66	192	435	95	315	619	147	368	615	292
IV. Opposing Car with *Illegal (raised) Beam*										
10 m.p.h.	74	146	303	88	255	520	103	298	580	233
20 m.p.h.	70	154	306	70	265	540	100	309	590	243
40 m.p.h.	59	140	301	74	236	510	117	297	520	224
Average		147			252			301		233
V. *With Test Car Only* (Check Run)										
20 m.p.h.	115	207	365	124	334	609	191	393	628	311

Note: Each figure given above is average of 39 tests made by 6 observers.

TABLE *A*-4.

Visibility Distances (ft.) for Dark-Clothes Condition and for 1" Red Reflector Buttons.

Pedestrian Wearing	No Reflector Button Dark Clothes.			1 Button o.			2 Buttons o o.			3 Buttons o o o.		
	Min.	Av.	Max.	Min.	Av.	Max.	Min.	Av.	Max.	Min.	Av.	Max.
I. *With Test Car Only*												
Rough Macadam	106	196	389	151	270	412	217	300	400	284	396	583
Smooth Macadam	92	195	546	200	283	347	225	320	359	307	415	480
Concrete	103	200	380	265	313	494	218	328	377	291	393	681
Average		197*			285			310			399	
II. Opposing Car with *Legal Normal Beam*												
Rough Macadam	63	166	337	83	221	294	124	238	353	234	330	453
Smooth Macadam	65	139	268	191	238	286	132	240	288	220	261	351
Concrete	88	172	293	216	279	311	270	304	359	200	324	515
Average		162			240			256			314	
III. Opposing Car with *Legal Depressed Beam*												
Rough Macadam	88	184	364	124	247	382	160	287	341	240	354	548
Smooth Macadam	82	178	297	206	233	261	189	264	304	240	307	592
Concrete	66	192	435	226	279	345	282	314	338	240	351	593
Average		185			253			290			345	
IV. Opposing Car with *Illegal (raised) Beam*												
Rough Macadam	31	125	313	85	188	294	100	212	294	166	288	440
Smooth Macadam	28	95	278	130	160	223	119	171	223	149	242	348
Concrete	68	147	303	194	244	509	194	248	294	190	281	431
Average		125			198			213			276	

* Average obtained by weighting visibility for each pavement by number of tests.

GLASS AS A DIELECTRIC.

BY

GEORGE W. MOREY.

The word glass does not connote a material of single, definite composition, but rather it is a generic term including a wide range of compositions, all of which are characterized by the fact that they represent liquids which have cooled through the range in which they normally would change to a crystalline conglomerate if equilibrium were attained, without that change having taken place. On cooling, the viscosity increases gradually and uniformly, until at ordinary temperatures the liquid solution is in all essential respects a rigid substance. The compositions which may be prepared as glass are limited only by the tendency toward devitrification, which sets definite limits, but within those limits the composition may be greatly varied. With the change in composition the electrical properties [1] change, and in particular the dielectric constant of glass changes over a range of more than four to one.

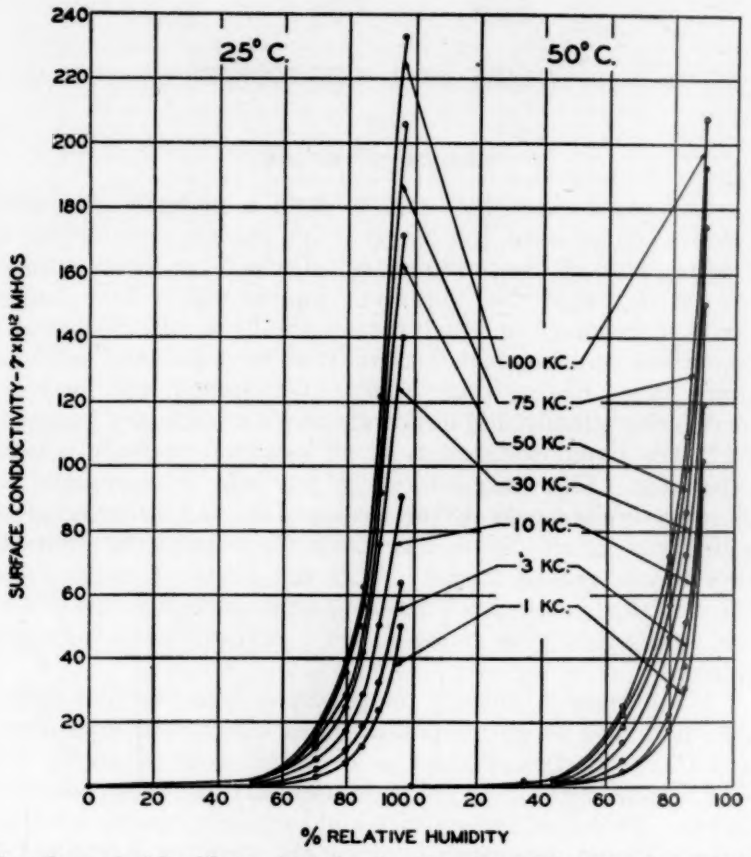
While glass at ordinary temperatures is an excellent dielectric, it is also at all temperatures an electrolytic conductor, and the properties of glass as a conductor of electricity will first be considered, In common with all other dielectrics, the factors of volume conductivity and surface conductivity must be considered separately. Since the time of Faraday [2] it has been recognized that part of the electrical conductivity of glass is to be ascribed to a film of moisture condensed on its surface. It was early demonstrated that near the dew point this film may reach a thickness of several millionths of a centimeter, that with the better glasses all of the film was removed in a dry atmosphere, and that with inferior glasses all of it could be removed only by heating. There is no

[1] The discussion in this paper is based on the book, "The Electrical Properties of Glass," J. T. Littleton and G. W. Morey, John Wiley and Sons, New York, 1933.

[2] M. Faraday, *Phil. Trans.*, 1830, part 1, p. 49.

* Average obtained by weighting visibility for each pavement by number of tests.

FIG. 1.



The surface conductivity of Pyrex resistant glass at 25° C. and at 50° C. for various frequencies as a function of relative humidity. After Yager and Morgan.

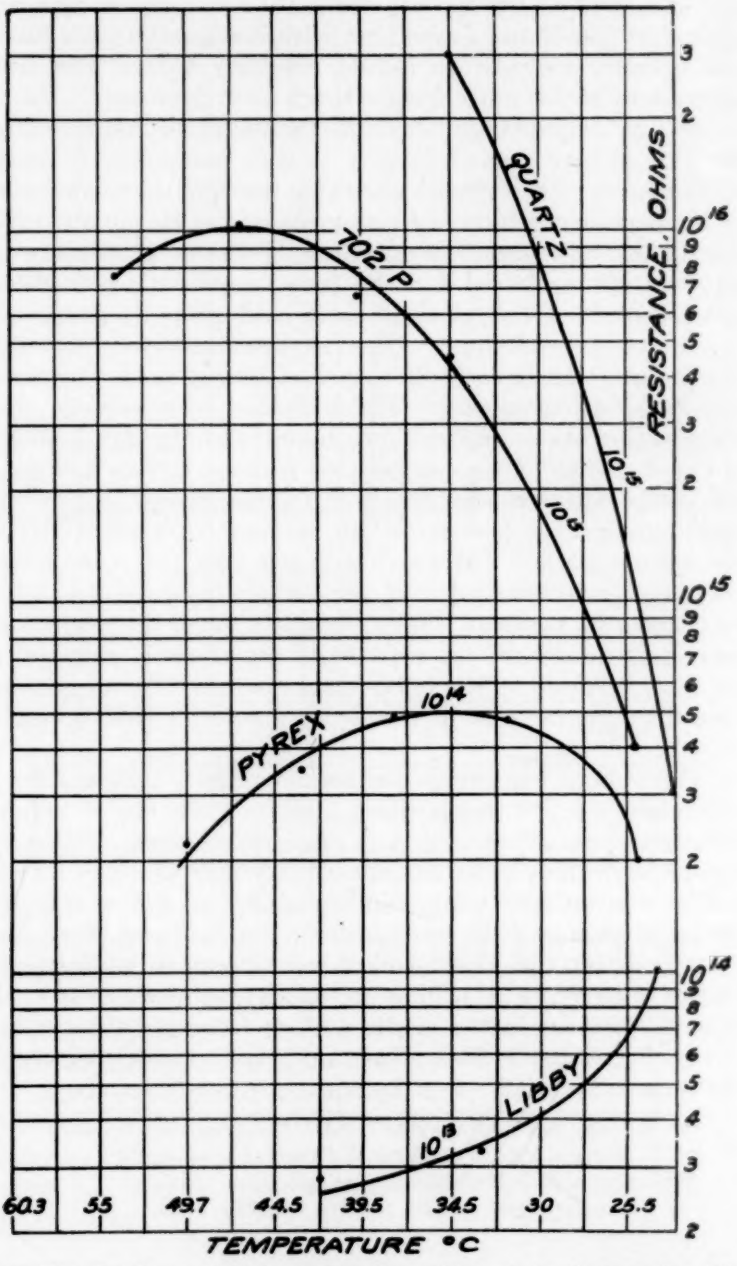
unanimity among investigators as to whether the film is monomolecular or polymolecular, or if the water is merely adsorbed or if some of it enters into solution in the surface layer. It is questionable, however, if the water spreads itself in a uniform layer over the surface of the glass. It appears more probable that certain areas representing predominatingly alkaline groupings will attract and hold a layer of water many molecules thick, while other areas will be essentially free from water. There would then be no continuous layer until the water condensed by the alkaline spots spreads out over the entire surface.

Yager and Morgan [3] studied the effect of both frequency and humidity on the surface conductivity of Pyrex resistant laboratory glass, and found that with low humidities 2 hours was usually sufficient to obtain constant values, but with higher humidities much longer times were necessary. At 30 kc. and 25°, equilibrium was not reached in 20 hours, and at 50° and 95 per cent. humidity it was impossible to reach equilibrium. Their results show that much of the earlier work on the surface conductivity is worthless from the quantitative standpoint. Bronson [4] found that the better glasses are all satisfactory insulators for the most sensitive electrometer tubes, provided the glass is clean and properly polarized. Cleanliness is paramount. Quartz (glass) insulators, mounted in vacuum, leaked badly if they had been touched with the fingers before mounting. The variation of resistance with temperature above ambient on a humid summer day is shown in Fig. 2. Clean glass can be used without serious leakage if the temperature is raised a few degrees above that of the surrounding air. The immediate increase in conductivity of the sample marked "Libbey" indicates that the volume conductivity predominated over the surface conductivity, while with the two types of Pyrex resistant glass the immediate decrease in conductivity represents the effect of removal of the film, followed as the temperature is raised by an increase caused by the increase in volume conductivity with temperature.

The volume resistivity of glass at ordinary temperature is dependent on the composition. Silica glass has a volume resistivity [5] at 22° of over 10^{18} ohm-centimeters. Pyrex resistant laboratory glass has at ordinary temperatures a resistivity of over 10^{14}, while the resistivity of Pyrex resistant electrical glass is of the order of 10^{16}. An ordinary plate glass has a resistivity of about 10^{12} ohm-centimeters, while special glasses may have a volume resistivity as low as 10^{3}. In general, increase in the alkali content increases the conductivity of glass, while ZnO, MgO, PbO, BaO, and CaO increase the resistivity,[6] their effect increasing in the order given.

[3] W. A. Yager and S. O. Morgan, *J. Phys. Chem.*, **35**, 2026 (1930).
[4] H. L. Bronson, cited by A. W. Hull, *Physics*, **2**, 420 (1932).
[5] H. L. Curtis, *Bull. Bur. Standards*, **11**, 359 (1914–15).
[6] M. Fulda, *Sprechsaal*, **60**, 769, 789, 810, 831, 853 (1927).

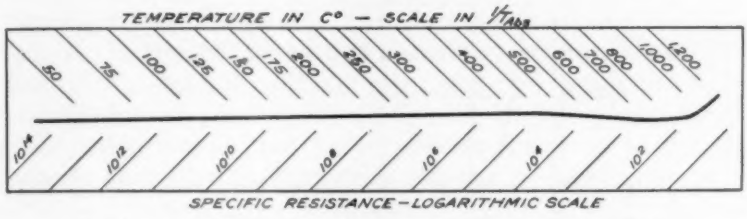
FIG. 2.



The variation of resistance with the temperature above ambient, on a humid summer day. After Bronson.

The electrical resistivity of glass decreases rapidly with increasing temperature, reaching about 10^4 ohms at the annealing temperature, and about unity at around 1200°. The complete curve for one glass [6] is shown in Fig. 3, in which the

FIG. 3.



The change in specific resistance of a glass with temperature. After Fulda.

logarithm of the specific resistivity is plotted against the reciprocal of the absolute temperature. As usually measured the curve shows a discontinuity at about the annealing temperature, and Fulda represents his results by two straight lines, each of which is represented by the formula

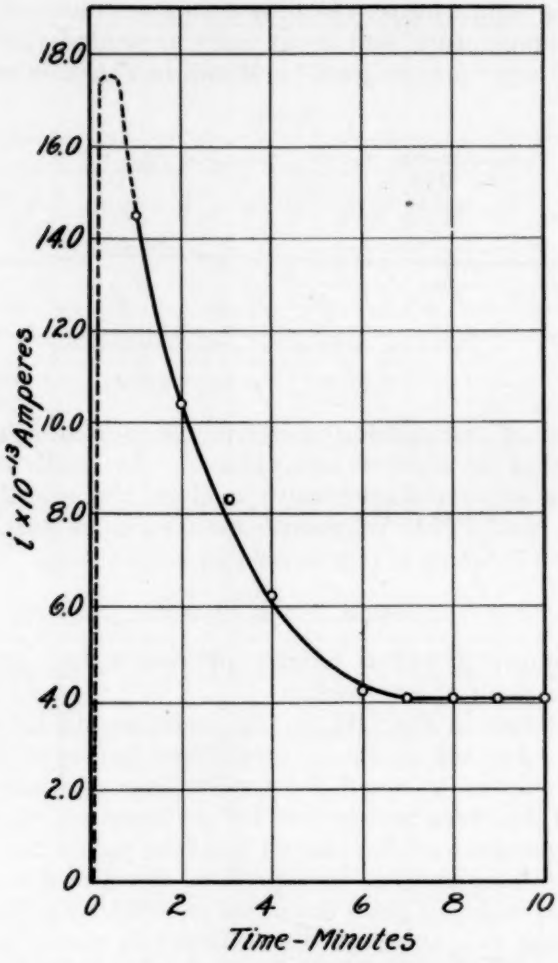
$$\log W = (A/T) + B$$

the constants A and B having different values above and below the point of intersection.

The break in the straight line relationship between log resistivity and the reciprocal of absolute temperature, which is usually found at about the temperature at which glass is annealed, has been assumed to be of theoretical significance. The temperature so determined has been called the "Transformation temperature," and has been considered to separate the region of liquid glass from that of solid. Littleton [7] has shown that this apparent discontinuity is caused not by a transformation but by the release of a frozen-in lag, and if the glass is maintained at each temperature until the conductivity has reached a constant value the curve becomes a smooth one, without a break. Using the then unpublished resistance measurements of K. Lark-Horowitz and C. L. Babcock, he compared the variation with temperature of the viscosity and the electrical conductivity, and found the vis-

[7] J. T. Littleton, *Ind. Eng. Chem.*, **25**, 748 (1933).

FIG. 4.



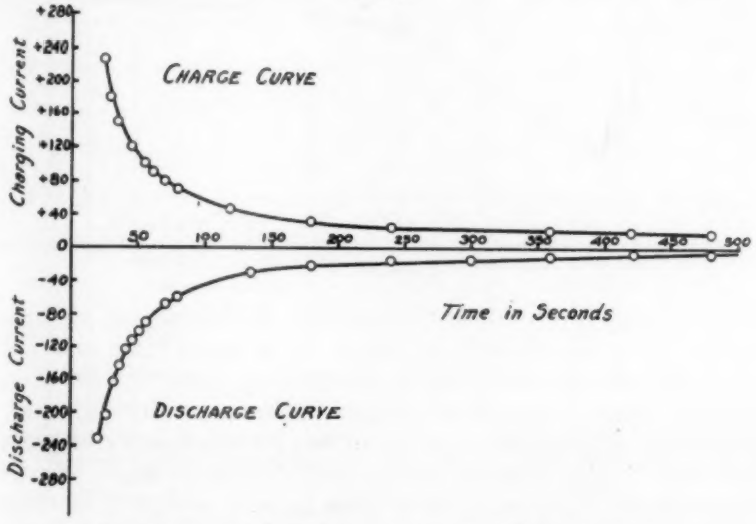
The complete charging curve of a glass. After Guyer.

cosity to vary with some power of the conductivity, the value of the exponent changing with the composition of the glass.

The measurement of the resistivity at low temperatures is greatly complicated by the dielectric absorption, a phenomenon first noticed by Benjamin Franklin, and later studied extensively by many observers. When an electromotive force

is impressed on glass, the current flow is not simply a function of the conductivity and the dimensions of the specimen, but is also an unknown function of the total elapsed time since the initial application of the voltage, and the previous electrical history of the glass. These effects are well shown by the recent work of Guyer.[8] Figure 4 represents the complete charging curve of a glass. The dotted portion, not drawn to scale, represents the first surge of current into the glass, which lasts only a few millionths of a second, and is determined by the capacity of the condenser formed by the glass sample. The steep downward portion represents the decay of the pure capacity current, and its merging into the reversible absorption current. This so-called anomalous current persists long after the purely geometrical charging current has disappeared, and merges into the flat portion of the curve, representing the normal conduction current. Figure 5 shows a typical charge

FIG. 5.



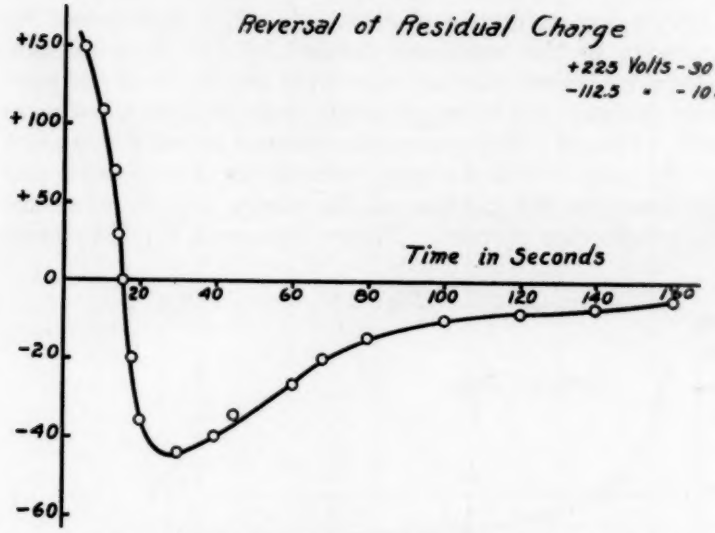
Typical charge and discharge curve of a borosilicate glass. After Guyer.

and discharge curve for a borosilicate glass. The discharge flows out of the glass after the charging battery has been disconnected and the sample temporarily short-circuited, and

[8] E. M. Guyer, *J. Am. Ceram. Soc.*, **16**, 607 (1933).

represents electricity which has been stored up in the glass, and which requires a considerable time for its complete discharge. Hopkinson [9] found that "the effects on the dielectric of past and present electric forces are superposable," or, to quote Lord Kelvin, "The charges come out of the glass in the order in which they go in." This effect is shown in Fig. 6.

FIG. 6.



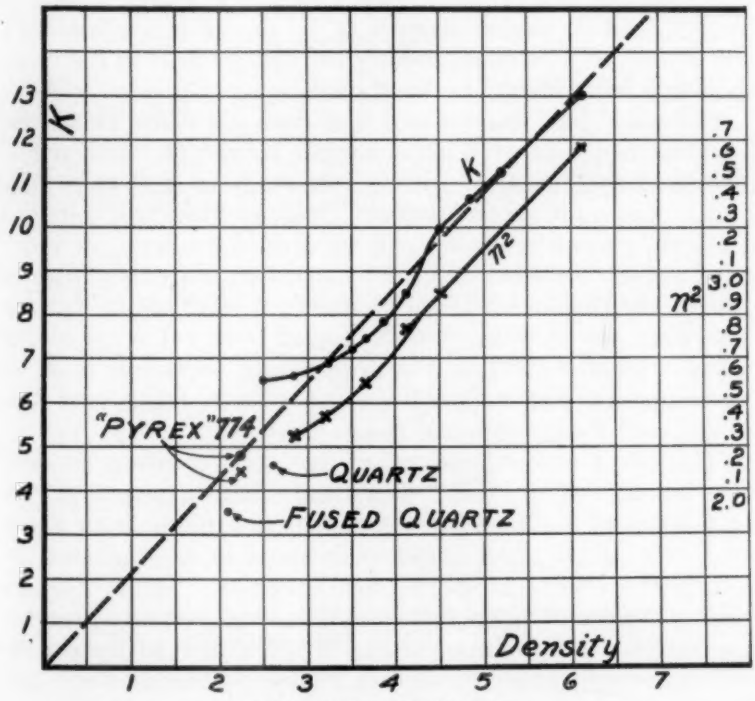
Reversal of residual charge in a borosilicate glass. The charging cycle is given in the figure; readings were taken after disconnecting the charging battery. After Guyer.

When during the process of charging the glass, the electromotive force is suddenly reversed for a short time and the electrode momentarily short-circuited to remove the pure capacity charge, a residual charge appears, producing a current which flows in one direction, then spontaneously reverses and flows in the other direction, then decays to zero. Measurements on the resistivity of glass may be seriously in error unless the absorption current is taken into account, as it may predominate over the conduction current, and persists for some time. Bronson found the apparent change in resistance due to the absorption current to be enormous during the first ten minutes, and to be appreciable after an hour.

[9] J. Hopkinson, *Phil. Trans.*, 1, 17 (1878).

The dielectric constant of glass will be discussed in its relation to the composition of the glass, temperature, and frequency. The early measurements of Hopkinson showed that with the ordinary crown-flint series of glasses the dielectric constant varied in a linear manner with the density. Thornton,[10] and later Addenbroke,[11] extended the series to heavier flints, Addenbroke measuring a glass of density 6.01, containing 78 per cent. PbO, 22 per cent. SiO_2. The results of these and other observers are included in Fig. 7, which also

FIG. 7.



Variation of K and n^2 with density.

contains results for silica glass, and for Pyrex resistant electrical glass. In the figure are summarized the available data on the relation between dielectric constant and density, and hence between dielectric constant and composition.

[10] W. M. Thornton, *Proc. Roy. Soc.*, **82**, 422 (1909).

[11] G. L. Addenbroke, *Phil. Mag.*, **45**, 516 (1923).

The Maxwell equations lead to the relations $n^2 = K$, where n is the refractive index of the medium, K the dielectric constant, and $R = (n - 1)^2/(n + 1)^2$, in which R is the reflecting power. Rubens [12] found the values of R computed from measurements of K agreed closely with the measured values. Since the above equations assume n and K to be measured for the same frequency, which was not the case, it follows that the dielectric constant is little affected by the frequency. Addenbroke[13] compared the density with n^2 for visible light and K at a frequency of 150 cycles per second in the measurements summarized in Fig. 7. He found K/n^2 varied from 2.75 to 3.55, and K varied from 6.57 to 13. For a glass with $K = 13$, $n^2 = 3.68$, consequently the change in K in the radio frequency band should be very small.

Sosman [14] has summarized the data on silica glass, the dielectric constant of which changes from 3.68, with a frequency of 250, to 3.80, with a frequency of 3×10^7. The results of several observers show that the dielectric constant of silicate glasses changes but little with frequency. Schott [15] found a slight decrease in K with increasing frequency in some glasses, the maximum change observed being about 1/2 per cent. when the frequency was changed from 1.9×10^5 to 10^6 cycles. MacLeod [16] found a $4\frac{1}{2}$ per cent. decrease in K as the frequency was varied from 500 to 10^6, using two lime glasses, and Pyrex chemical resistant glass.

The effect of temperature on dielectric constant has not been adequately studied. Gray and Dobbie measured [17] K for a series of 8 glasses, at temperatures ranging from about 10° C. to 140° C., and found an increase in most glasses, although the results are somewhat irregular. Strutt [18] measured the effect of temperature on K at different frequencies. His results are reproduced in Fig. 8. For each frequency the dielectric constant increases with increasing temperature, and

[12] H. Rubens, Sitzber. kgl. preuss. Akad. Wiss., 1916, II, 1280.

[13] Op. cit.

[14] R. B. Sosman, "The Properties of Silica," Chemical Catalog Co., New York, p. 616 (1927).

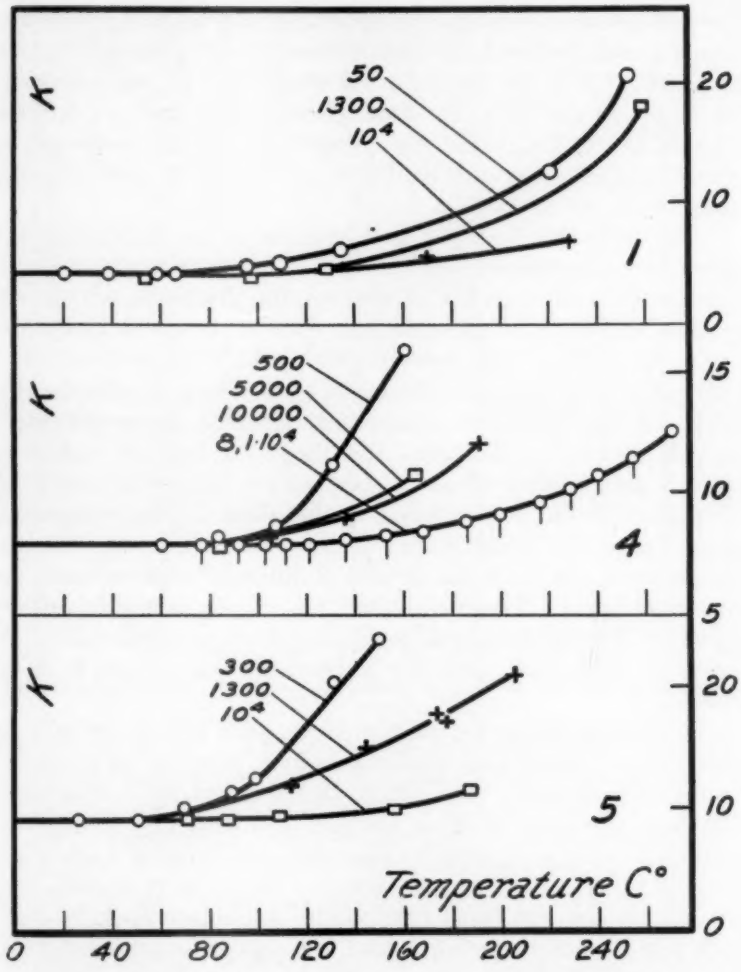
[15] E. Schott, *Jahrb. drahtl. Tel.*, **18**, 82 (1921).

[16] H. J. MacLeod, *Phys. Rev.*, **21**, 53 (1923).

[17] A. Gray and J. Dobbie, *Proc. Roy. Soc. London*, **63**, 38 (1898).

[18] M. J. O. Strutt, *Arch. Electrotech.*, **25**, 715 (1931).

FIG. 8.



Dependence of K on temperature at various frequencies. After Strutt.

at low frequencies the displacement current rapidly becomes masked by the conduction current. Glass I, which was a borosilicate probably similar to Pyrex chemical resistant glass, should have had a higher electrical resistance than the glasses 4 and 5, which were a soda-lime and a heavy lead glass, respectively, and should be less affected by temperature.

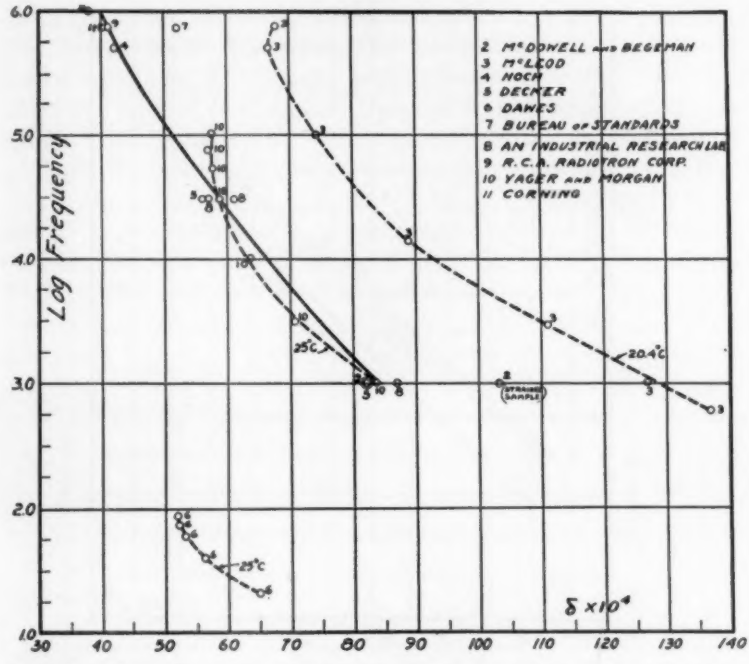
This conclusion is in harmony with the experimental results. The maximum operating temperature for a glass condenser thus depends both on the composition of the glass and on the frequency. For low frequencies about 80° C. approximates the limit of stability for lime glasses and 120° C. for the borosilicate types, while for frequencies of the order of 10^4 cycles lime glass is practically constant up to 140° C., and borosilicate up to 240° C.

The dielectric loss per unit volume of an insulating material has been shown by Hoch [19] to be proportional to the frequency, to the square of the voltage gradient, and to the product of the dielectric constant, K, and the phase difference angle, δ. Sin δ is the power factor, and the phase angle, θ, is $(90 - \delta)$. Two general classes of glass are available for the study of the dielectric properties, namely, those having a high K and a low δ value, and those having low values of both K and δ, since these properties are separately alterable by change in the composition of the glass. The accuracy of measurement of small power-factor values is not great, and comparisons between the results of different observers are not always reliable. Figure 9 shows the power factor-frequency curve of Pyrex chemical resistant glass as determined by different observers, and the agreement leaves much to be desired.

In general the power factor varies with the electrical conductivity of glass, and variables which increase the conductivity will increase the power factor. Schott [20] concluded that heavy metals such as barium and lead give low power factors and high dielectric constants, and that a high alkali content gives a high power factor. Borosilicate glasses with low alkali content, and containing no heavy metals, have both low dielectric constant and low power factor, and hence low dielectric losses. The large increase in power factor resulting from high alkali content is shown by the results of Decker,[21] who studied several types of commercial glasses, and determined their composition by analysis. The susceptibility of the surface of the glass to attack by moisture is an

[19] E. Hoch, *Bell System Tech. J.*, 1, 110 (1922).
[20] E. Schott, *Jahrb. drahtl. Tel.*, 18, 82 (1921).
[21] W. C. Decker, *Elect. World*, Mar. 19, 1927.

FIG. 9.

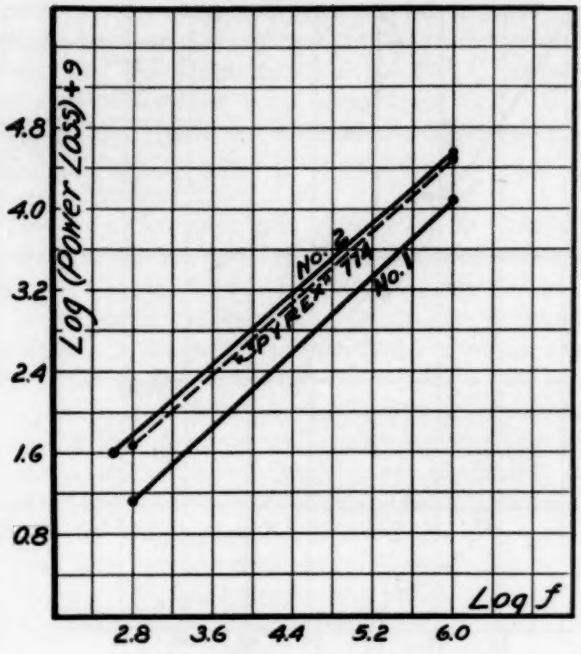


Power factor-frequency. Pyrex chemical resistant glass. Data from various laboratories.

important factor. The high lead and high barium glasses, as well as all glasses with a high alkali content, tend to weather badly, and are attacked by atmospheric moisture.

The experimental results on the effect of variation of frequency on power losses are far from satisfactory. In addition to the large experimental error inherent in measurement of low-loss glasses, the comparison of the results of different observers is made difficult by the usual failure to give definite information as to the compositions of the glasses measured. In general it may be said that with some glasses the power factor increases with frequency, in others it decreases, and there is a possibility of the existence of inversion points on the power factor-frequency curve. That such inversion points exist has not been proved, however, and it is possible that in some of the measurements the possibility of dielectric heating has not been sufficiently considered. The measure-

FIG. 10.



Power loss—frequency. After MacLeod.

ments of MacLeod [22] are shown in Fig. 10. Glasses 1 and 2 are lime glasses. He found the power factor to decrease by a factor of from 2 to 3 as the frequency was increased from 500 to 10^6 cycles. MacLeod gives the following equation expressing his experimental results for the relation between power factor and frequency:

$$\delta = D/f^{(k-n)/2}$$

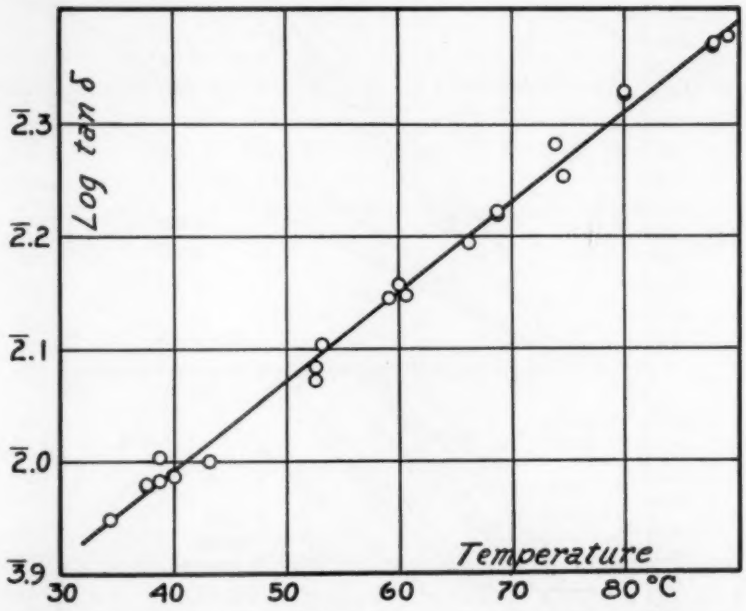
The values of k, n, and D for the three glasses are as follows.

	k.	n.	D.
Glass 1	1.095	0.90	0.00714
Glass 2	1.13	0.86	0.0373
Pyrex chemical resistant glass	1.15	0.885	0.0264

[22] H. J. MacLeod, *Phys. Rev.*, **21**, 53 (1923).

The power factor increases rapidly with rise in temperature, resulting in an increased rate of energy absorption. As the temperature increases the dielectric heating increases, and eventually the system becomes unstable and breakdown occurs. Schott found that the loss angle begins to increase fairly rapidly after the temperature of 100° is reached, and at 340° C. it has increased to about 40 times the value at 20° C. for a wave length of 1600. Schott also found the power factor to decrease with temperature because of the increase of both the conduction current and the absorption current. McDowell and Begeman [23] corrected their power loss measurements for the part due to conductivity, with the results shown in Fig. 11. Strutt found a linear relationship between

FIG. 11.

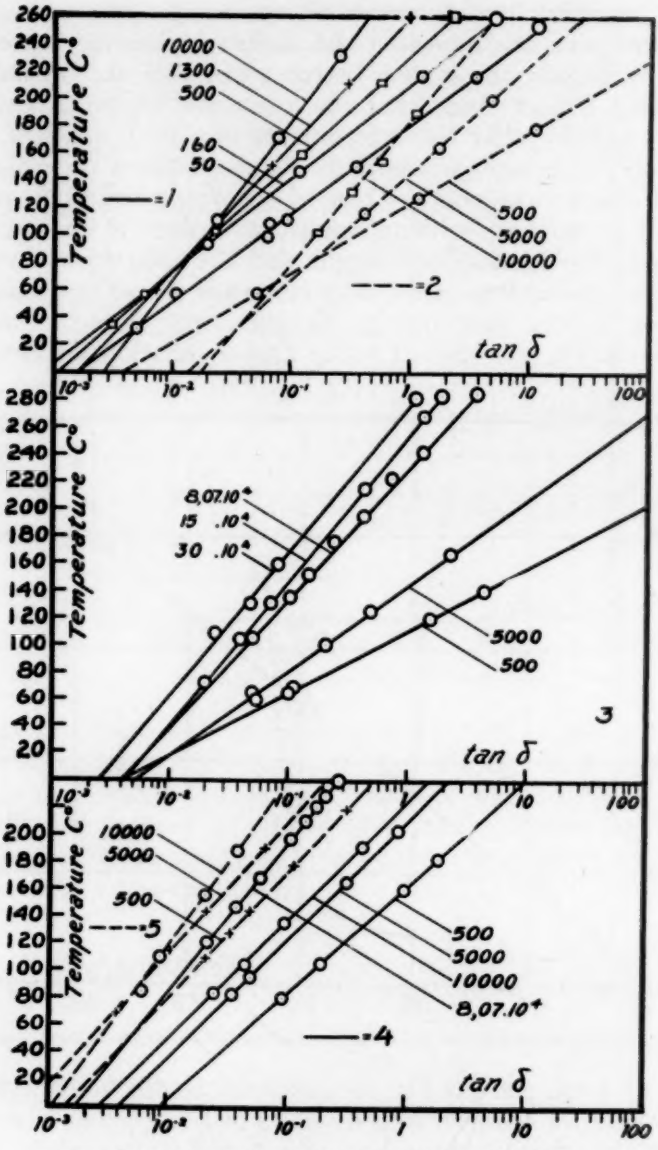


Power factor (corrected for conduction loss)—temperature. After McDowell and Begeman.

log tan δ and the absolute temperature, as did McDowell and Begeman for their corrected values of tan δ. The curves of Strutt are reproduced in Fig. 12.

[23] L. S. McDowell and H. L. Begeman, *Phys. Rev.*, 33, 55 (1929).

FIG. 12.



Power factor at various frequencies—temperature. After Strutt.

GEOPHYSICAL LABORATORY,
CARNEGIE INSTITUTION OF WASHINGTON,
June, 1934.

A SEMI-DETERMINATE CAM PROBLEM REQUIRING UNUSUAL MATHEMATICAL TREATMENT.

BY

THEODORE M. EDISON,

Research Engineer, Calibron Products, Inc., West Orange, New Jersey.

SUMMARY.

A method of producing a cam which will always be in two-point contact with an oscillating follower is developed in comparatively general terms in connection with the design of a pump. The contacting portions of the follower are, however, limited to circular arcs of equal radius. A method of computing ideal rates of flow is discussed.

The following analysis of an empirically developed pump was undertaken at the request of the Multicycol Pump and Engine Corporation of New York with the object of eliminating undesirable clearances occurring at certain points in the pump's cycle of operation.

The state of the development, when it was first brought to our attention, is roughly indicated in Fig. 1, where successive

FIG. 1.

relative positions of a rotating cam and an oscillating follower are shown. Pumping action was obtained through the variation in the space enclosed between the cam and follower. In addition to these parts, there were, of course, end plates and suitable valving ports which were covered and uncovered at appropriate times by the moving members.

There were two serious difficulties with the pump shown above. (1) No satisfactory way had been found to avoid

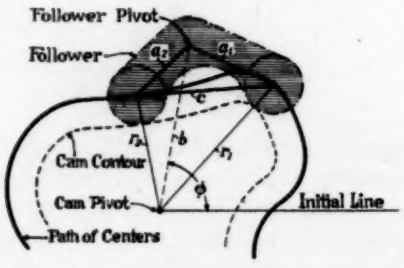
excessive leakage when gaps appeared between the cam and follower at certain points in the cycle. (2) The cam cut through the center of oscillation of the follower (see Fig. 1*e*) so that the follower could not be mounted on a continuous shaft. This made necessary the use of an undesirable structure.

While the primary purpose in presenting this development to us was to obtain an analytical solution of the first named difficulty, we were told that the second was quite important and further, that a two-lobed cam (if one could be found) might offer a number of advantages over the three-lobed cam previously used.

At first, the chance of obtaining satisfactory solutions of the problems appeared to be rather slim, as repeated attempts to set up general differential equations for the contours of the cam and follower ended in failure. However, when an entirely different approach was used, the reason for the trouble was soon found—certain portions of the contours can be arbitrary within very wide limits. Because of the extreme complexity of any comprehensive formulae, it was deemed advisable to introduce two simplifying limitations, and a successful method of handling the problem was then devised, as outlined below.

(1) *Limitation.*—Consideration will be confined to followers having convex contacting portions which are circular arcs of equal finite radius. (See Fig. 2.)

FIG. 2.



(2) *Limitation.*—It will be assumed that the centers of the two circular contacting portions of such a follower remain on opposite sides of, (and never cross), a straight line passing

through the cam pivot and the center of oscillation of the follower. (This merely avoids the need of investigating possible double valued functions and arrangements in which the follower is not self locking.)

A very great simplification may be made by virtue of Limitation (1).—In Fig. 2, suppose that the cam is held stationary and that the follower is moved around it. The centers of the follower circles will then trace the path shown and it is evident that the position of the follower may be defined just as well from this curve as from the actual points of contact with the cam. It is, therefore, possible to ignore the cam entirely and deal directly with the curve representing the path of centers of the follower circles, provided that the following rule is observed:

(3) *Rule.*—The radius of curvature of the path of centers of the follower circles, when directed into the cam, must not be less than the radius of the follower circles (and there must be no "bottle neck" small enough to trap the follower circles).

In the next portion of this analysis the troublesome variable points of contact between the cam and follower will be eliminated from consideration, as described above.

The follower is assumed to be a rigid solid, so that its two arms (a_1 and a_2—or a—in the figures), remain in a fixed relation to each other, and the distance c between the centers of the follower circles is a constant. The distance b between the effective pivots of the cam and follower is also constant. To simplify the drawings, it will be assumed in this argument that the follower pivot moves counterclockwise through an angle ϕ from a fixed initial line (Fig. 2), while the path of centers remains stationary. It is now easy to establish the following theorem in regard to the distances (r_1 and r_2) of the ends of the follower arms from the cam pivot.

(4) *Theorem.*—r_1 increases as r_2 decreases, and vice versa.

The proof is not given as it is quite evident from an inspection of the trigonometry of Fig. 2, in view of Limitation (2).

(5) *Corollary.*—When r_1 is a maximum, r_2 is a minimum, and vice versa.

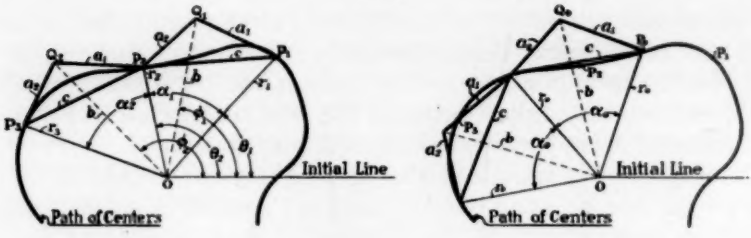
Suppose, now, that P_1, Fig. 3, is the point on the curve of centers at which r_1 has the largest value that it assumes in

the course of a complete cycle. Next suppose that the follower advances until the center of the follower circle which was formerly at P_1 reaches P_2. At the same time, the center formerly at P_2 advances to the new maximum [1] point P_3, at a distance r_3 from the axis of the cam.

(6) *Definition.*—P_2 and P_3 and similar points progressively determined as described above (Fig. 3) are defined as minimum and maximum points, respectively, *corresponding* to the maximum point P_1. "Corresponding" will also be used in referring to values of r occurring at those points, or to any set of "progressively determined" points or values of r, (r_1, r_2, $\cdots$, r_i).

(7) *Theorem.*—All maximum values of r corresponding to its greatest value are equal.

FIG. 3.



a b

Proof: Suppose that r_1 at P_1 (Fig. 3) is the greatest value assumed by r and that it is greater than r_3 at P_3. This implies that the corresponding minimum value of r preceding P_1 is less than r_2 at P_2, in view of Theorem (4), and this, in turn, implies that the corresponding maximum value of r preceding P_1 is greater than r_1 at P_1. But this is impossible, as r_1 at P_1 was previously selected as the largest value assumed by r in the course of the entire cycle. For the same reason, r_3 at P_3 can not be larger than r_1 at P_1. Therefore, all maximum values of r corresponding to r_1 at P_1 must be equal.

(8) *Theorem.*—The angular spacing of consecutive corresponding points at which the values of r are alternately largest and smallest (α_1, α_2, $\cdots$, Fig. 3*a*) is the same as the

[1] Not necessarily a true mathematical maximum.

angular spacing of consecutive corresponding points at which the values of r are equal (α_0, Fig. 3*b*).

Proof: As $r_1 = r_3$ in Fig. 3*a*, triangles r_1cr_2 and r_2cr_3 are congruent and therefore $\alpha_1 = \alpha_2$ (if r_1 has its greatest value). For the same reason, it is evident that all points of greatest and least radius corresponding to P_1 must be equally spaced. Furthermore, if the cam is not to degenerate into a circle, the number n of points of greatest radius corresponding to P_1 (Fig. 3) must be finite and, therefore, it must be possible to start from P_1 and return to the identical point after $2n$ equal corresponding steps.

In view of continuity requirements, there must be, in each of the $2n$ intervals, P_1P_2, P_2P_3, P_3P_4, $\cdots$, at least one point at which the value of r is equal to the next corresponding value of r, and each such point implies a similar corresponding point in the next interval. Thus it is possible to start with any one of these points, such as P_0, in the interval P_1P_2, and return to a point P_0' in the same interval, after $2n$ equal corresponding steps. If the radius at P_0 is r_0, the radius at P_0' will also be r_0. P_0' must either coincide with P_0 or it must be angularly displaced from it by some amount ϵ. In the latter case it would be possible to start at P_0', repeat the process just described, and return to P_0'' displaced from P_0 by the amount 2ϵ. Furthermore, there is no limit to this repetition, so that eventually a point $P_0''\cdots'$ would be reached which would no longer fall within the interval P_1P_2. But this is not consistent with the above logic and must be rejected. Therefore P_0' must coincide with P_0 and $\alpha_0 = \alpha_1 = \alpha_2$.

(9) *Theorem.*—The length of each arm of the follower must be equal to the distance between the pivots of the cam and follower. ($a_1 = a_2 = b$ in Fig. 3.)

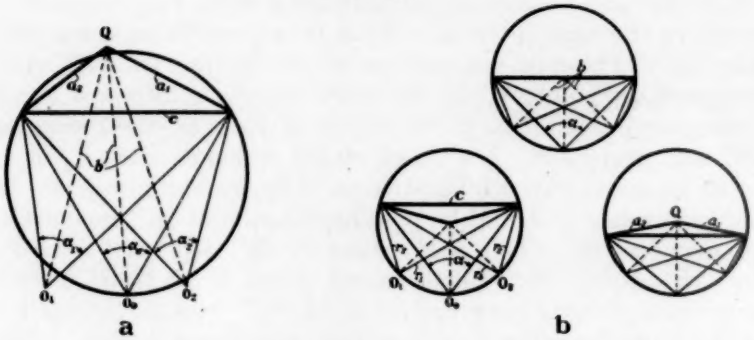
Proof: The four triangles lettered a_1a_2c in Fig. 3 are identical. Suppose them to be superimposed and redrawn in Fig. 4*a*. Then Q_0, Q_1, and Q_2 (Fig. 3) will coincide at Q (Fig. 4). Suppose, further that the cam pivot O is redrawn in the three positions, relative to c, which it occupied in Fig. 3 —as indicated at O_0, O_1, and O_2, Fig. 4. Next suppose that a circle is drawn through O_0 and the ends of the line c. Since the three *equal* angles, α_0, α_1, and α_2, have the cord c in com-

mon, they must be measured by the same arc, and therefore O_1 and O_2 should have fallen on the circle through O_0. Hence it appears that Q, which is by hypothesis equi-distant from O_0, O_1, and O_2, is incorrectly drawn in Fig. 4*a* and that it must actually be located at the center of the circle. When this correction is made, one of the three possible configurations shown in Fig. 4*b* will result and in each case $a_1 = a_2 = b$, as was to be proved.

(10) *Note.*—Hereafter, the single letter a may be used in place of a_1, a_2, or b, and α may be used in place of α_0, α_1, or α_2.

(11) *Theorem.*—The line c (Fig. 3) subtends a constant angle at the cam pivot irrespective of the relative positions of the follower and the cam.

FIG. 4.



Proof: By Theorem (9) and an inspection of Fig. 4*b*, it is seen that the cam pivot O will always fall on the circle centered at Q and having the radius a, no matter how the follower moves relative to the cam, within the limits of (2). Therefore the angle α is constant, as it is always measured by the same arc.

(12) *Theorem.*—r_3 (Fig. 3) will always be equal to its corresponding radius r_1 as the point P_1 advances along the path of centers.

Proof: The truth of this theorem may be determined by studying Figs. 3 and 4. It will be noticed in Fig. 4b that any value of r_1 implies a corresponding value of r_2 which in turn implies a corresponding value of r_3 identical with r_1.—See proof of Theorem (11).

(13) *Theorem.*—The path of centers (and therefore the cam) must consist of a finite number (n) of equally spaced, congruent corresponding lobes. [A "corresponding lobe" is considered to extend over the angular range 2α, even though sub-lobes may be included in that range.]

Proof: If P_1 is advanced along any possible path, its corresponding point P_3 will advance along a duplicate path angularly displaced from the path of P_1 by the amount 2α. This is a direct consequence of Theorems (11) and (12). The number of lobes may be determined by reasoning similar to that set forth in the first paragraph of the proof of Theorem (8).

(14) *Theorem.*—The entire path of centers is determined by specifying an arbitrary path over a continuous range of θ (Fig. 3) of $180/n$ degrees, where n, the number of *corresponding* lobes of the cam, is numerically equal to the numerator of the fraction $180/\alpha$ when α is expressed in degrees and the fraction is reduced to its lowest terms in integers.

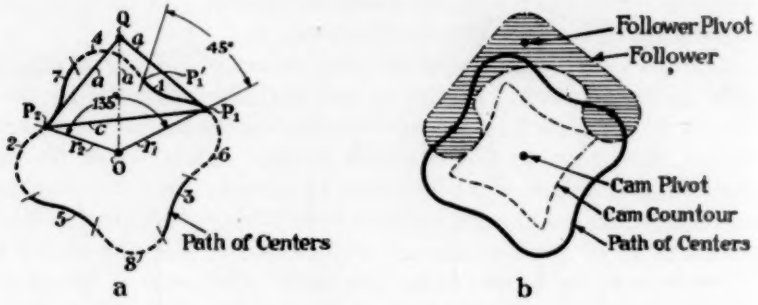
Proof: Corresponding maximum values of r occur at intervals of 2α degrees. If 360 is not divisible directly by 2α, it may be necessary to advance several times around the cam before returning to the starting point. Thus, if m is the minimum number of revolutions required, $360m/2\alpha$ *distinct* corresponding maximum values of r will be determined. But the number of such maximum values of r is also the number of corresponding lobes of the cam and therefore $n = 360m/2\alpha$ or $n/m = 180/\alpha$, where m has its smallest integral value.

Since an actual path of centers can cover only 360°, portions of the n corresponding lobes which overlap (when $m > 1$) must coincide. Hence, in any practical case, the cam must consist of n congruent *primary* lobes, each covering $360/n$ degrees. The path of centers is arbitrary over only $180/n$ degrees, however, because values assigned to r over one half of the primary lobe angle *determine* definite corresponding values of r over the other half.—The following example will make clear the significance of this theorem.

(15) *Example.*—Suppose that $\alpha = 135°$. The fraction $180/\alpha$ then becomes $180/135$ which reduces to $4/3$ and therefore, by (13) and (14), the cam must consist of four similar corresponding lobes. (See Fig. 5.) Since $n = 4$, Theorem

(14) indicates that the entire cam will be determined by specifying an arbitrary path for a continuous range of $180°/4 = 45°$. Thus, in Fig. 5*a*, suppose that path 1, covering 45° between P_1 and P_1', is arbitrary. If P_1 is now allowed to advance along path 1, P_2 will advance along (and therefore determine) path 2. In the same way, if P_1 is allowed to follow path 2, P_2 will determine path 3, which, by (13), will be a duplicate of path 1. By repeating this process seven times the entire path of centers is progressively determined, as indicated by the path numbers in Fig. 5*a*, and on the eighth repetition, P_2 will retrace path 1. A study of Fig. 5*a* shows that an attempt to specify more than 45° of the path of centers results in overlapping of the "arbitrary" portion with a generally dissimilar curve—an obvious absurdity.

FIG. 5.



The *total* number of lobes on the cam may be increased by introducing secondary lobes into the portion of the curve which is arbitrary. That is the reason for italicizing the word "corresponding" in Theorem (14).

The problem of finding the value of α when n is given is relatively simple. Since each lobe covers $360/n$ degrees, as noted above,

$$\alpha = \frac{360}{n}\left(q + \frac{1}{2}\right), \tag{16}$$

where $(q+1/2)$ is the number of "primary" lobes bridged by the follower (q being an integer in the range $0 \leqq q < n/2$) and α is measured in degrees.

Although the conditions under which a cam and follower may be kept in two point contact have been established [2] in relatively broad terms, the actual shape of the cam is still undefined. A considerable amount of detailed theory was developed relating to accelerations, the restrictions of Rule (3), the avoidance of concavities in the cam contour, the conditions under which cams are symmetrical, and actual methods of cam construction. While this work presents a number of unusual features, it is relatively conventional and is, therefore, omitted.

* * *

Using the general analysis, several different cam and follower arrangements were roughly designed and submitted to the Multicycol Pump and Engine Corporation. They selected the two-lobed cam for further investigation and suggested that, in addition to the variable area between the cam and follower, external areas (such as *A*, *C*, *D*, Fig. 6*a*) be included

FIG. 6.

in the pumping action. The cycle of such a pump is indicated in Fig. 6 by diagrams showing successive positions of the cam and follower. *E* and *F* are the discharge and intake ports respectively. It will be noticed that area *D* and almost all of area *B* are swept out each *half* revolution of the cam so that the capacity of the pump is relatively large.

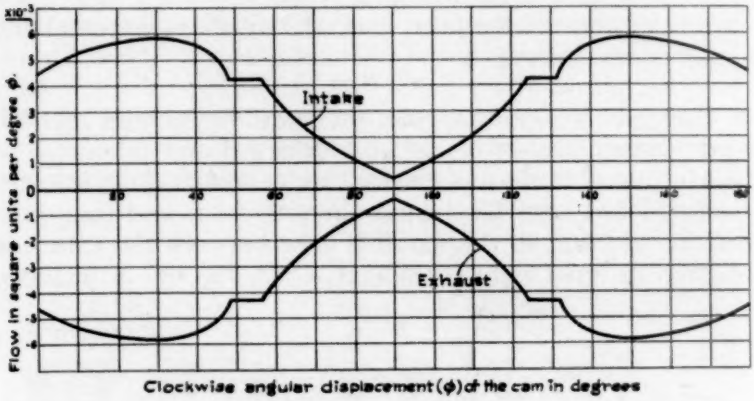
Mr. Wilber B. Huston,[3] after checking the theory, made a number of detailed studies of its application to the proposed

[2] If, contrary to (1), the radius of the follower circles is made infinite, the expression "path of centers" loses its significance and a remarkable special case develops when $\alpha = 180°$. The simplest example of this kind is the familiar eccentrically mounted circular cam rotating in a yoke with parallel sides. The position of the follower pivot is almost unrestricted and even extremely asymmetrical locations are practical. Such special cases are interesting, but space limitations prevent discussion of them here.

[3] Research Engineer, Calibron Products, Inc.

pump and drew up specifications for the cam which was actually constructed. The contour of this cam is approximated in Fig. 6. The theoretical flow characteristics of the pump are indicated in Fig. 7—where $\phi = 0$ when the cam is in the position shown in Fig. 6*a*.

FIG. 7.



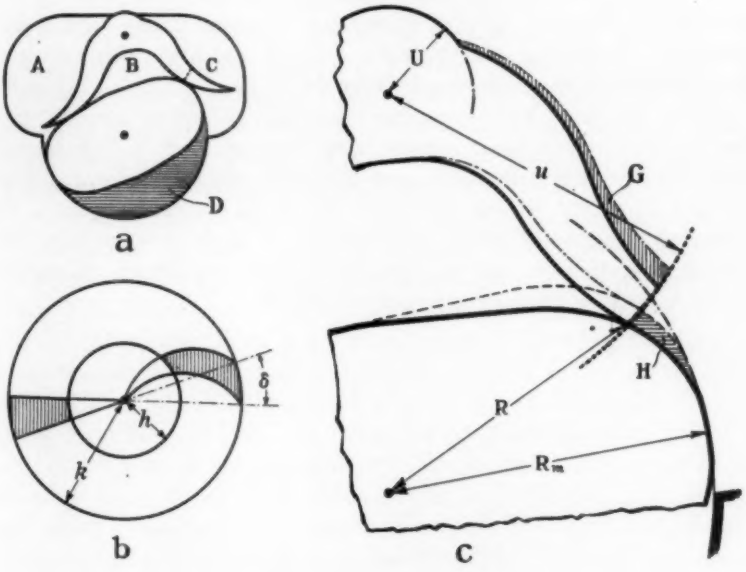
The curves of Fig. 7 may be found by (*a*) making planimeter measurements of the areas *A*, *B*, *C*, and *D* (Fig. 6*a*) with the cam in various positions (using an enlarged template), (*b*) plotting these areas, suitably combined, against the angular displacement ϕ of the cam, and (*c*) determining the rate of change of the proper areas by graphical differentiation of the curves mentioned in (*b*). However, the foregoing method is open to the objection that slight inaccuracies in planimeter measurements cause large errors in the velocity curves and this led to the use of an alternative procedure which eliminated the measurement of areas entirely.

Referring to Fig. 8*a*, note that for an infinitesimal displacement of the cam the shaded area *D* may be considered to be part of the cam and, therefore, may be neglected in determining the rate of change of area *C* at the point shown. The end of the follower beyond the cam contact (the portion cut off by the dotted line in Fig. 8*a*) may also be neglected since, for an infinitesimal displacement, it merely moves as a unit in the area *C*. The actual increment of *C* is the sum

of the two infinitesimal areas represented by G and H in the enlarged and more detailed Fig. 8*c*, where u is the distance from the follower pivot to the point of contact between the cam and follower.

Aside from second order terms, which drop out when displacements approach zero, the areas G and H are generated by angular displacements of curved lines about the follower and cam pivots respectively. It is not hard to find straight lines which, when substituted for the curves, will generate

FIG. 8.



equivalent areas for equivalent displacements. For example, in Fig. 8*b* each of the two shaded areas must be equal to $\pi(k^2 - h^2)\delta/360$ (δ being expressed in degrees), since a complete revolution of either the curved line or the straight radius would sweep out the same washer-shaped area between the two circles. In the same way $G = \pi(u^2 - U^2)d\sigma/360$ and $H = \pi(R_m^2 - R^2)d\phi/360$, where $d\sigma$ and $d\phi$ (in degrees) represent infinitesimal clockwise angular displacements of the follower and cam respectively and U and R_m are constants.

Thus

$$(17) \quad dC = G + H = \pi(u^2 - U^2)d\sigma/360 + \pi(R_m^2 - R^2)d\phi/360$$

and

$$(18) \quad dC/d\phi = [(u^2 - U^2)d\sigma/d\phi + R_m^2 - R^2]\pi/360.$$

A little study will show that (18) holds for all values of ϕ. Similar reasoning leads to the same type of formulae for the areas A and B.

The constant U is entirely arbitrary within practical limits and may be altered without upsetting any other part of the analysis. The Multicycol Pump and Engine Corporation has proposed changing the value of U to improve the original flow characteristics shown in Fig. 7.

The distance between the cam and follower pivots was one inch in the pump which was constructed. The model was made with sufficient precision to reduce the total lost motion to about $\pm$ .001 inch for all positions of the cam. In tests, the pump showed a surprisingly high volumetric efficiency, ran quietly and was comparatively free from vibration up to speeds of more than 3,000 R.P.M.

THE GRAPHICAL TRANSFORMATION OF CURVES INTO STRAIGHT LINES AND THE CONSTRUCTION OF ALIGNMENT CHARTS.

BY

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1. *Introduction.*—Practically the whole literature on Nomography is concerned exclusively with the problem of constructing alignment charts to represent certain types of equations. A good deal of engineering data, however, is obtained empirically and is available only in the form of tables or sets of curves. As far as could be ascertained, the problem of constructing charts for such data or curves is not mentioned anywhere in the literature. Another problem closely related to that of alignment charts, is that of the transformation of curves into straight lines by changing the coördinate system. A familiar example of this type is the transformation of the family of curves $Y = AX^n$ into straight lines by the use of logarithmic paper. This problem was also never considered with reference to an empirical set of curves, although it is of great practical value. It may happen, for instance, that a few curves of a one-parameter family are well established from routine tests, while there are only available a few points for other values of the parameter. If the well established curves could be transformed into straight lines by a change in the coördinate system, it would require only two well established points for any value of the parameter to determine the whole curve.

2. The problems treated in this paper may be formulated as follows:

Given a one-parameter family of curves obtained empirically, it is desired if possible

(*a*) To transform these curves into straight lines by using coördinate paper which carries either one or two function scales instead of uniform scales, and

(*b*) To construct an alignment chart representing these curves.

The paper is divided into three parts. In part I are developed methods for testing a given family of curves whether it can be transformed into straight lines by means of one function scale, and also methods for carrying out the transformation. Part II deals with the same problem but with two function scales. The methods of constructing alignment charts are given in part III.

PART I.

The Transformation of Curves into Straight Lines by a Single Function Scale.

3. We assume that all the curves of the family are continuous and monotonic. The variables are U, V, and W, where the curves are plotted in the (V, W) plane and U is the parameter which determines any particular curve. In order to avoid circumlocution we shall say that a family of curves is "lineal" if it can be transformed into straight lines by a single function scale; "bilineal" if it can be transformed into straight lines by means of two function scales only, and "non-lineal" if it cannot be transformed into straight lines at all.

The general analytic expression for a one-parameter family of curves is

$$f(U, V, W) = 0. \tag{1}$$

In order that the curves be lineal, equation (1) must be of the form

$$W = F(U) + G(U) \cdot H(V) \tag{2}$$

or

$$V = F'(U) + G'(U) \cdot H'(W). \tag{2'}$$

We shall consider only eq. (2), and all results obtained obviously apply to (2') if we make the proper interchange of the variables V and W. If the equation of the curves is known, the problem is rather trivial, as we can easily determine whether it can be put in the form of eq. (2), and then if we graduate the V scale proportional to $H(V)$, and leave the W scale uniform, the curves will plot out as straight lines. Our problem consists in dealing with empirical curves. We want to devise a test for lineality and develop a method of

transformation without attempting to find the equation of the curves.

4. *Test for Lineality.*—Consider any two curves C_1 and C_2 corresponding to the values of the parameter U_1 and U_2 (see Fig. 1). At the points V_0 and V_0' along the V axis draw two lines L and L' parallel to the W axis. Let the intersections of C_1 with L and L' be W_1 and W_1' respectively, and the intersections of C_2, W_2 and W_2' respectively. Let

$$\Delta W_1 \equiv W_1 - W_1',$$
$$\Delta W_2 \equiv W_2 - W_2'.$$

Then the necessary and sufficient condition, that the curves shall be lineal is that the ratio $\Delta W_1/\Delta W_2$ shall remain the same no matter what points V_0 and V_0' are chosen.[1] In order that the whole family of curves shall be lineal, the above condition must be satisfied for every pair of curves of the family.

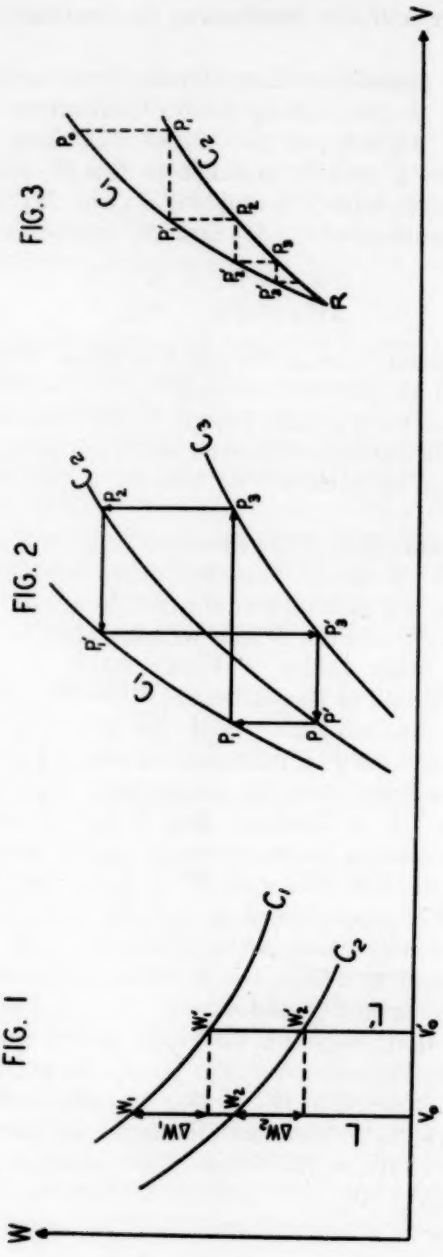
5. *The Construction of the Function Scale.*—If the condition for lineality is satisfied, then the function scale V^* may be constructed in the following manner. Pick out any curve C, take any point V_0 on the V axis which will be kept fixed, and graduate the other values of V say $V_1, V_2, \cdots V_n$, at distances proportional to the values of $W_1 - W_0, W_2 - W_0, \cdots W_n - W_0$ on the curve C.[2] With this function scale V^*, the curve C will obviously be transformed into a straight line, and due to the constant ratio all curves will necessarily become straight lines. It is obvious that if only a single curve is given, it can always be transformed into a straight line, by constructing the function scale V^* as described above.

6. *Method of Approximation.*—If the ratio $\Delta W_1/\Delta W_2$ does not stay absolutely constant, it is often possible to obtain an approximate function scale for V which will yield satisfactory results. The method is as follows:

We pick again a point V_0 which is left unchanged, but now, instead of graduating $V_1, V_2 \cdots V_n$ at distances proportional to $W_1 - W_0, W_2 - W_0, \cdots W_n - W_0$ along *any* curve, we graduate them at distances proportional to the mean values of $W_1 - W_0, W_2 - W_0, \cdots W_n - W_0$ obtained

[1] See appendix 1.

[2] See appendix 2.


V
W
C1
C2
C3
FIG. 1
FIG. 2
FIG. 3
W1
W2
V1
V2
ΔW1
ΔW2
P0
P1
P2
P3
P'
P'1
P'2
P'3
R

from all curves. This method will often yield a function scale for V, such that the plotted curves will very closely approximate straight lines.

PART II.

The Transformation of Curves into Straight Lines by Means of Two Function Scales.

7. We make the same assumptions about the curves as in Part I. In order that the curves shall be bilineal, eq. (1) must be of the form

$$M(W) = F(U) + G(U) \cdot H(V). \tag{3}$$

Again if the equation is known, all we have to do is to graduate the W scale proportional to $M(W)$, and the V scale proportional to $H(V)$ and the curves will plot out as straight lines. We have to devise a test and a method of transformation for empirical curves.

8. *Test for Bilineality.*—It will be shown later that if we are given only two curves they can always be transformed into straight lines by means of two function scales, so that our test must involve at least three curves. Consider any three curves, C_1, C_2, C_3 corresponding to the values of the parameter U_1, U_2, and U_3, and such that C_2 lies between C_1 and C_3 (see Fig. 2). Pick out any point $P(V, W)$ on C_2 and make the following sequence of projections:

Project P vertically on C_1 into P_1 (V, W_1),
Project P_1 horizontally on C_3 into P_3 (V_3, W_1),
Project P_3 vertically on C_2 into P_2 (V_3, W_2),
Project P_2 horizontally on C_1 into P_1' (V_1', W_2),
Project P_1' vertically on C_3 into P_3' (V_1', W'),
and Project P_3' horizontally on C_2 into P' (V', W').

If the points P and P' coincide for all points on C_2 then the three curves are said to have the closure property.[3] Now for three curves having a common point, the closure property is a necessary and sufficient condition for bilineality.[4] In order that a whole family of curves with a common point shall be bilineal, the closure property must be satisfied for

[3] A. Wertheimer, *Bulletin American Math. Soc.*, Vol. XL (1934), p. 79.

[4] See appendix 3.

any three curves of the family. We shall confine our studies then only to families of curves that have a common point, as no satisfactory solution was found for any other case.

9. *The Construction of the Function Scale W**.—We assume that all curves pass through a common point R. We take any two curves C_1 and C_2 such that C_1 lies above C_2 (see Fig. 3). Now starting with P_0, we build up the step system by the following sequence of projections.

Project P_0 vertically on C_2 into P_1,
Project P_1 horizontally on C_1 into P_1',
Project P_1' vertically on C_2 into P_2,
. . . . . .

We keep up this process, approaching the point of intersection R as a limiting point.

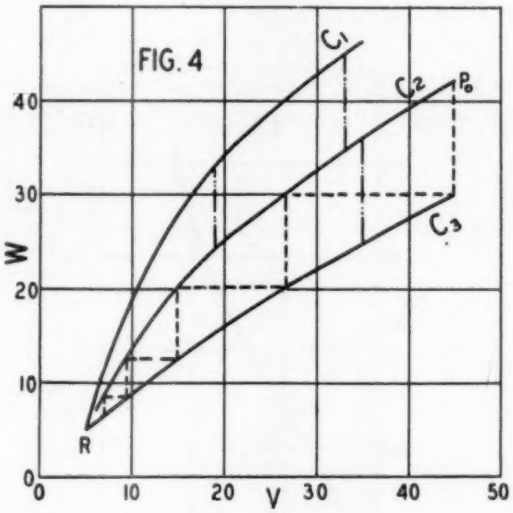
Let us denote by W_r the value of W at R, and by W_0, W_1, $W_2 \cdots W_n$ the values of W corresponding to the points P_0, P_1, $P_2 \cdots P_n$ respectively. Let $W_0 - W_r = d$, then to construct the function scale W^*, we keep the points W_0 and W_r fixed, and graduate the points W_1, W_2, $W_3 \cdots W_n$ at distances from W_r proportional to Kd, K^2d, $\cdots K^nd$ respectively, where K is any number greater than zero and less than one. This gives us the graduations for n values of W.[5] To obtain the graduations for all values of W, we have to interpolate graphically—or by any other method—between these n points and thus establish the complete W^* scale. This will give a scale W^* in which the distances for corresponding points on C_1 and C_2 will always be in a constant ratio. Due to the closure condition there will also be a constant ratio between corresponding points on any other two curves. Hence, if we succeed in transforming one curve into a straight line, the others will necessarily become straight lines.

10. *The Function Scale V**.—Once the W^* scale is established we obtain the V^* scale in the following manner. We keep fixed the point V_r, that is, the point V which corresponds to the common point of the curves. To graduate the other points, say V_1, V_2, $V_3 \cdots V_n$, we obtain the corresponding distances $W_1^* - W_r^*$, $W_2^* - W_r^* \cdots W_n^* - W_r^*$, from any

[5] See appendix 4.

curve C and graduate the values of V proportional to those distances. This will obviously transform the curve C into a straight line. and hence all curves will be transformed into straight lines.

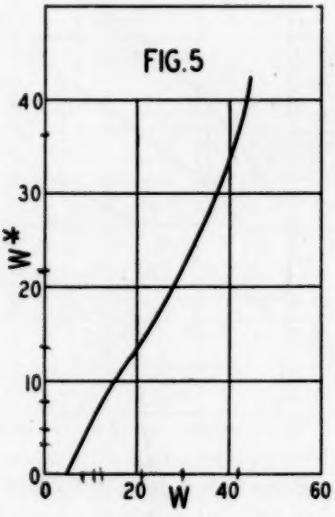
If two curves only are given, even if they do not intersect, we can always extend them to an intersection and then construct the V^* and W^* scales as described above. Hence, any arbitrary two curves can always be transformed into straight lines.



11. *The Interpolation for the W^* Scale.*—In Fig. 4 are shown three curves C_1, C_2 and C_3, satisfying the closure condition very closely. If we were to use C_1 and C_3 for the construction of the W^* scale we would get only a few points and too far apart, so we use C_2 and C_3. For the point P_0, $W = 42$ and for the point R, $W = 5$, so the distance $d = 37$. Let us take $K = 0.6$, then we get the following table:

W.	W^*.
42	37.0
30	22.2
20.3	13.3
12.6	8.0
8.7	4.8
6.9	2.8
5.0	0

From the plot of these points as shown on Fig. 5, we see that even now the points for $W = 30$ and $W = 42$ are too far apart for graphical interpolation. It would be well to have a point in between, say $W = 36$. We draw the curve temporarily up to $W = 30$. We then enter C_2 with $W = 36$ and find the corresponding point on C_3 is $W = 25$. From the temporary curve we see that for $W = 25$, $W^* = 17$. As the assumed ratio of 0.6 must hold for any corresponding points on the curves C_2 and C_3, we have for $W = 36$, $W^* = 17.0/0.6 = 28.3$. This permits us then to complete the curve up to $W = 42$.



The curve C_1, however, goes up to $W = 45$ and we have to extend our curve out there. To do this, we enter C_1 say with $W = 33$, the corresponding point on C_2 is $W = 24$. From the curve we have

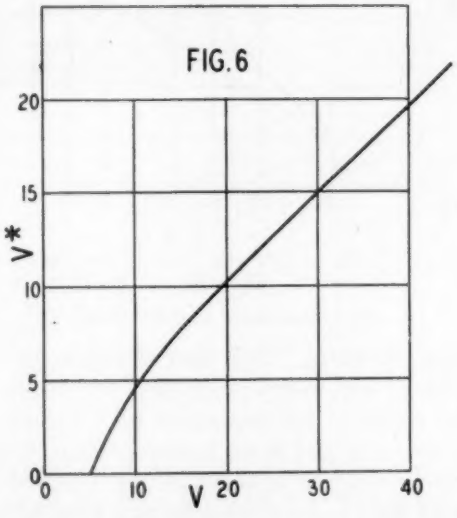
$$W = 33, \qquad W^* = 25; \qquad W = 24, \qquad W^* = 16.$$

Therefore, the ratio for corresponding points on C_1 and C_2 is $25/16 = 1.56$. Entering C_1 with $W = 45$, the corresponding point on C_2 is $W = 34.5$. From the curve we have for $W = 34.5$, $W^* = 27.2$, hence, for $W = 45$, $W^* = 27 \times 1.56$

= 42.2. This completes our curve which we use for graduating the W^* scale. To complete the illustration, we will now determine the V^* scale. We use the curve C_3, keep the point $V = 5$ fixed and we get the following table:

V.	W.	$W^* - W_5^* = V^*$.
5	5	0
10	8.9	4.7
15	12.3	7.8
20	16.0	10.3
25	19.1	12.6
30	22.1	14.9
35	25.0	17.0
40	27.6	19.5
45	30	22.0

The plot of these points is shown in Fig. 6. We now graduate the scales W^* and V^* from Figs. 5 and 6 respectively and we

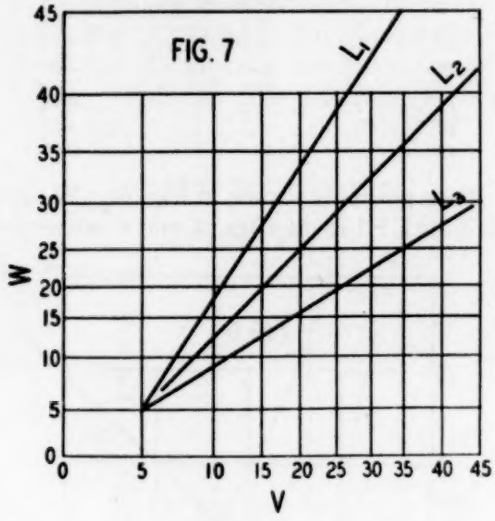


get on Fig. 7 the three lines L_1, L_2 and L_3 which correspond respectively to the curves C_1, C_2 and C_3 of Fig. 4.

12. *Method of Approximation.*—If the closure condition is not absolutely satisfied, it is still often possible to obtain approximate function scales which will yield satisfactory results. We construct the W^* scale in the same way as described in paragraph 9, but instead of graduating the V^*

scale proportional to $W_1^* - W_r^* \cdots W_n^* - W_r^*$ on any curve, we graduate it proportional to the mean values of $W_1^* - W_r^*$, $W_2^* - W_r^* \cdots W_n^* - W_r^*$ obtained from all curves.

THESE STRAIGHT LINES CORRESPOND TO THE CURVES ON FIG. 4



PART III.

The Construction of Alignment Charts.

13. Strictly speaking, it is not possible to construct an alignment chart for every conceivable family of curves. However, the form of the equation of a family for which a chart can be constructed is so general,[6] that it is believed to be possible to construct a satisfactory chart for practically every family of curves occurring in practice.

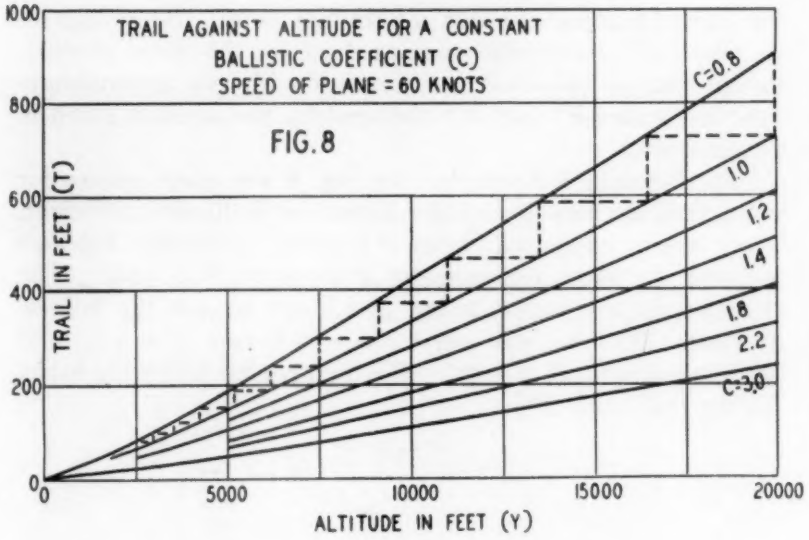
For lineal or bilineal families, charts can always be constructed.[7] All we have to do is to graduate the obtained function scales V^* and W^*, on parallel lines and then obtain the U scales by intersections.

14. *Methods of Approximation.*—If the curves are neither

[6] See appendix 5.

[7] See appendix 6.

lineal nor bilineal, we can still almost always construct a satisfactory chart by a method of successive approximation. We give two methods. The bilineal method assumes as a first approximation that the curves are bilineal and hence can be applied only to curves passing through a common point. The lineal method assumes as a first approximation that the curves are lineal and hence theoretically can be applied to any family of curves. However, for practical reasons, this method is not satisfactory when the curves pass through a common point, and should not be used then.



15. *The Lineal Method.*—We construct the approximate function V^* as given in paragraph 6. We graduate this V^* scale and the uniform W scale on parallel lines, and determine the U scale by intersections. Due to the curves not being strictly lineal, these intersections will, as a rule, not determine unique points, but some configurations. The centers of these configurations will have to be used as first approximations to the U scale.

Second Step.—Once the approximate U scale is established, we redetermine either the V or the W scale by intersections

from the other two. Which one of the scales should be attacked first will become apparent after trying one or two points, as it will be found the intersections will converge much closer for one of the scales than for the other.

Third Step.—Assuming that the V scale was redetermined in the second step, the W scale can now be redetermined—if it results in any improvement—by working with the U and V scales. As a last step, it should be tried if any improvement in the U scale is possible by working with the other two. The chart will then, as a rule, be found to be quite satisfactory.

16. *The Bilineal Method.*—This method can be used only for curves passing through a common point. The steps to be taken are exactly the same as those for the lineal method, except that in this case we start out with two approximate function scales V^* and W^* obtained by the method given in paragraph 12.

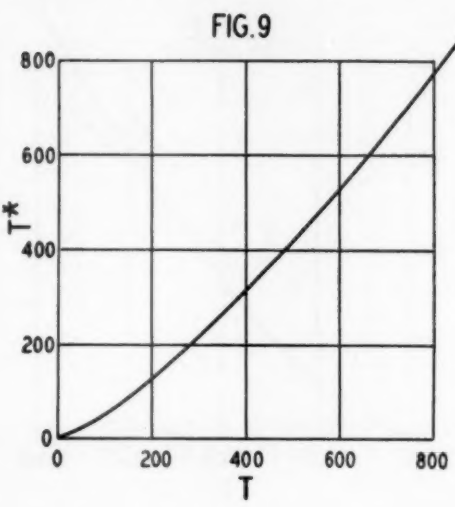
17. *Illustrative Example.*—In Fig. 8 are given curves for bomb trail against altitude for a constant Ballistic Coefficient. They were computed from "Exterior Ballistic Tables," Volume 1. War Department Document No. 1107. The curves have a common point, and hence we use the bilineal method. We use the curves $C = 0.8$ and $C = 1.0$, and assume the ratio $K = 0.75$. We then get the following table, for the trail scale T^*;

Trail.

(T.)	(T*.)
910	910
731	682
589	512
470	384
375	288
300	216
242	162
193	121.5
154	91.2
122	68.4
100	51.3
83	38.5
70	28.9
58	21.7

We complete the T^* scale by graphical interpolation, as shown in Fig. 9.

FIG. 9



Using the T^* scale, we get the following table for the altitude scale Y^*:

Y. / C.	2000.		6000.		10000.		14000.		16000.		18000.		20000.	
	T.	T^*.	T.	T^*.	T.	T^*.	T.	T^*.	T.	T^*.	T.	T^*.	T.	T^*.
0.8	61	23	232	151	421	327	610	531	710	651	810	780	910	910
1.0	51	19	189	113	338	248	491	400	570	488	650	580	732	680
1.2	41	13	158	90	281	192	409	315	475	381	540	451	610	531
1.4	33	11	131	70	240	159	350	259	405	311	462	370	520	430
1.8	28	9	100	48	185	111	270	183	313	222	360	269	404	311
2.2	21	6	82	38	150	82	220	140	258	174	295	205	332	241
3.0	18	5	61	23	110	53	161	91	190	115	216	138	243	162
Mean		12.3		75.1		167.4		274.1		334.6		399.0		466.4

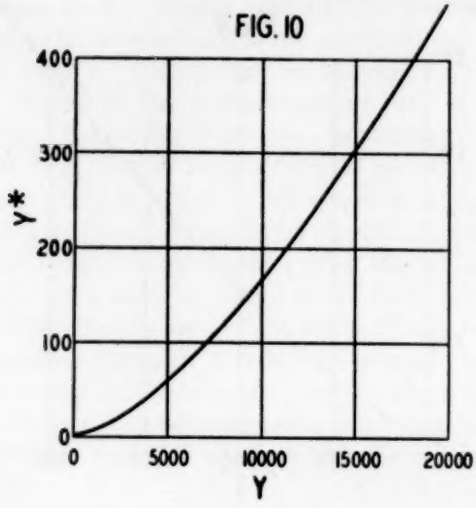
In the above table:

Y = altitude in feet,
C = ballistic coefficient,
T = trail in feet.

The Y^* scale is to be graduated proportional to the above means. The plot is shown in Fig. 10.

We now graduate the T^* and Y^* scales on parallel lines and obtain the approximate C scale by intersections. Working now with the scales of trail and ballistic coefficient, we redetermine the altitude scale, and the final chart is shown

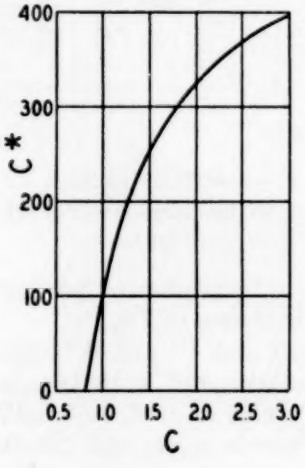
FIG. 10



on Fig. 12. It might have been possible to improve its accuracy by trying to redetermine the trail and ballistic coefficient scales, but it was considered good enough for an illustration.

18. *The Lineal Method.*—The same curves as on Fig. 8 are shown on Fig. 13 plotted for a constant altitude so that

FIG. 11



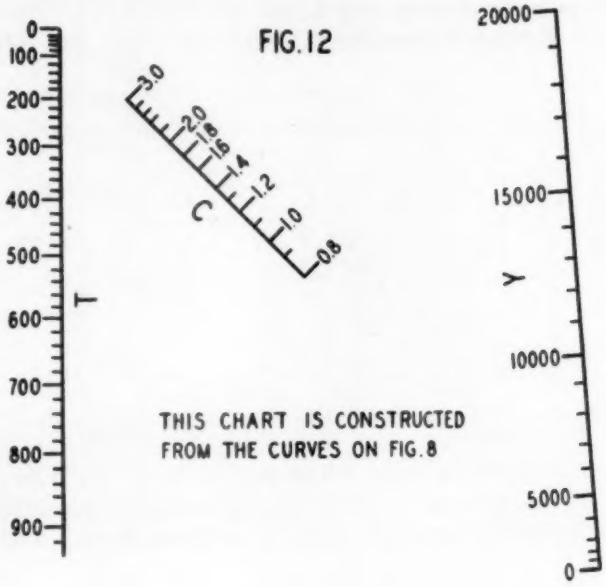


FIG. 12
0
100
200
300
400
500
600
700
800
900
T
3.0
2.0
1.8
1.6
1.4
1.2
1.0
0.8
C
20000
15000
10000
5000
0
Y
THIS CHART IS CONSTRUCTED
FROM THE CURVES ON FIG. 8

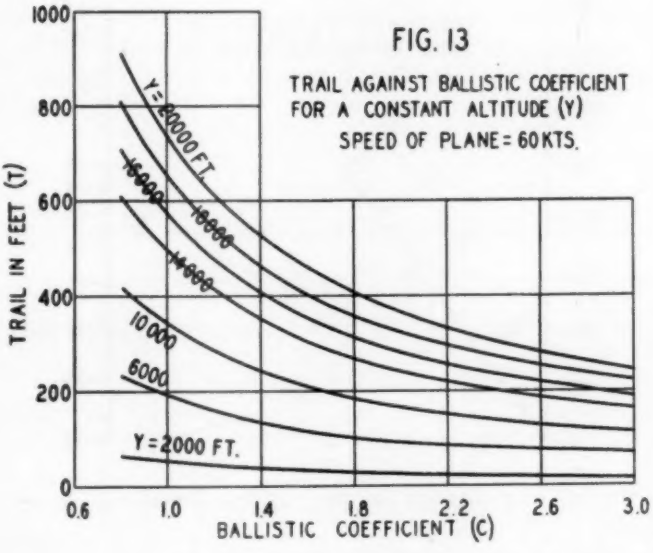
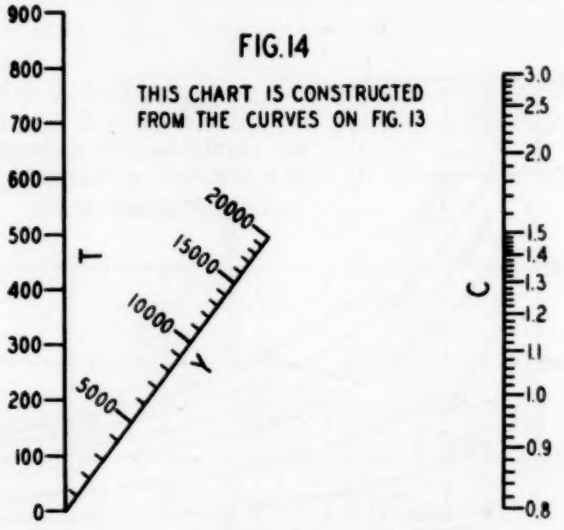


FIG. 13
TRAIL AGAINST BALLISTIC COEFFICIENT
FOR A CONSTANT ALTITUDE (Y)
SPEED OF PLANE = 60 KTS.
TRAIL IN FEET (T)
1000
800
600
400
200
0
Y = 20000 FT.
16000
12000
14000
10000
6000
Y = 2000 FT.
0.6
1.0
1.4
1.8
2.2
2.6
3.0
BALLISTIC COEFFICIENT (C)

they have no common point and we can apply the lineal method. To determine the C^* scale we have the following table:

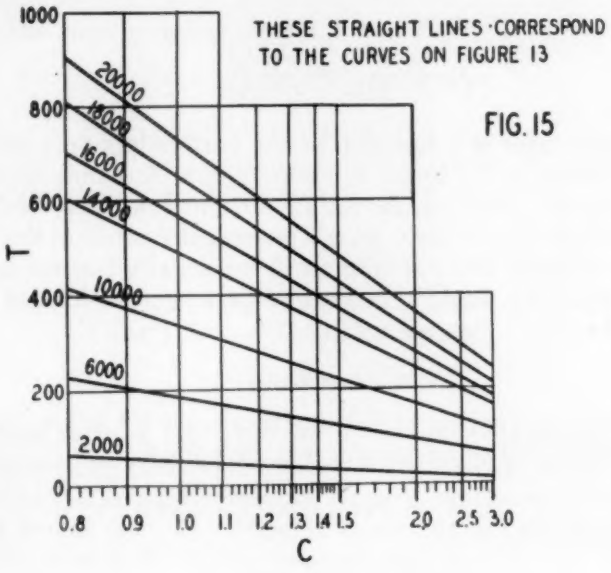
Y. \ C.	0.8.	1.0.	1.2.	1.4.	1.8.	2.2.	3.0.
			$T_c - T_{0.8}$				
20000	0	176	300	390	505	588	662
18000	0	158	268	348	448	513	591
16000	0	140	235	308	398	452	520
14000	0	118	200	260	338	390	448
10000	0	82	140	180	234	270	310
6000	0	43	74	100	131	147	170
2000	0	12	22	28	35	41	45
Mean	0	104.1	177.0	230.6	298.4	343.0	392.3

The plot of the C^* scale is shown on Fig. 11. We now graduate the C^* scale, and a uniform trail scale on parallel lines, and determine the altitude scale by intersections. The chart



is shown on Fig. 14; no further approximations were found necessary.

On Fig. 15, are shown the curves of Fig. 13 transformed



into straight lines by using the function scale C^* and a uniform trail scale.

19. In general, if we can plot the curves so as not to have a common point it is always advantageous to do so, as the lineal method is easier to apply and yields, as a rule, a more satisfactory chart.

* * * * * *

APPENDIX 1.

If the curves are lineal then their equation must be

$$W = F(U) + G(U) \cdot H(V).$$

We then have on Fig. 1

$$W_1 = F(U_1) + G(U_1) \cdot H(V_0)$$

and

$$W_1' = F(U_1) + G(U_1) \cdot H(V_0').$$

Therefore

$$\Delta W_1 = G(U_1) \cdot \{H(V) - H(V_0')\}.$$

Similarly

$$\Delta W_2 = G(U_2) \cdot \{H(V) - H(V_0')\}.$$

Hence

$$\frac{\Delta W_1}{\Delta W_2} = \frac{G(U_1)}{G(U_2)}.$$

Thus the ratio is a function of the parameters only and does not depend on V, hence it must remain constant along any two curves. But this is also a sufficient condition, because if the ratio stays constant, then if we transform one of the curves into a straight line the others will necessarily become straight lines, and any single curve can always be transformed into a straight line. (See paragraph 5.)

APPENDIX 2.

The construction of the function scale V^* follows directly from the equation of the curves. We have

$$W = F(U) + G(U) \cdot H(V)$$

or

$$H(V) = \frac{W - F(U)}{G(U)}.$$

We have then on any curve, that

$$H(V_n) - H(V_0) = \frac{W_n - W_0}{G(U)}.$$

Thus the graduations for the V^* scale should be proportional to the set of values $W_n - W_0$ on any curve.

APPENDIX 3.

That the closure property is a necessary condition, follows directly from the theorem in the paper referred to in footnote (3). To prove that this condition is also sufficient, we show that when the closure property is satisfied, then if a scale W^* is established such that there is a constant ratio for corresponding points on two curves, then there will also be a constant ratio for corresponding points on any other two curves.

In Fig. 2, assume that we have established a W^* scale such that there is a constant ratio K between C_2 and C_3. Let us find the ratio K' for corresponding points on C_1 and C_2.

From the corresponding points P and P_1 we have

$$K' = W^*/W_1^* = W^*/KW_2^*.$$

Now let us denote by $P_2'(V_2', W_2')$, the point of intersection of the line $P_1'P_3'$ with the curve C_2. From the corresponding points P_2' and P_3' we have that

$$W_2' = W^*/K.$$

If we now determine again the ratio between C_1 and C_2 from the corresponding points P_1' and P_2' we get,

$$K' = W^*/KW_2^*.$$

Thus the ratio is the same at those two points, and as by hypothesis the closure condition is satisfied at every point, the ratio will remain the same for any pair of corresponding points on C_1 and C_2. Similar reasoning shows that there will be a constant ratio for any two curves.

APPENDIX 4.

The method of constructing the W^* scale can be arrived at directly from the consideration that the curves are bilineal and have a common point. The equation of such a family of curves is,

$$M(W) = G(U) \cdot H(V).$$

Consider the points P_0 and P_1 in Fig. 3, we have

$$M(W_0) = G(U_1) \cdot H(V),$$
$$M(W_1) = G(U_2) \cdot H(V).$$

Therefore

$$M(W_0)/M(W_1) = G(U_1)/G(U_2).$$

Thus the ratio is independent of V and is a function of the parameters only, hence it must be a constant for any two curves. It still remains to show, that we may assume for the ratio any arbitrary value.

It is obvious that if we raise every term in the equation to the same power, the curves will remain unaltered. We may then assume that the equation of the curves is

$$[M(W)]^r = [G(U) \cdot H(V)]^r,$$

where r is any arbitrary number. We then have

$$[M(W_0)/M(W_1)]^r = [G(U_1)/G(U_2)]^r.$$

Now for any arbitrarily assumed value of K there always exists a unique value of r which satisfies the equation

$$[G(U_1)/G(U_2)]^r = K,$$

namely,

$$r = \log K/\log [G(U_1)/G(U_2)].$$

Thus the assumption of an arbitrary value for K is equivalent to assuming an arbitrary value for the exponent r.

APPENDIX 5.

In order to be possible to construct a chart for a one parameter family of curves, the equation must be of the form

$$\begin{vmatrix} A(W) & B(W) & 1 \\ C(V) & D(V) & 1 \\ E(U) & L(U) & 1 \end{vmatrix} = 0,$$

where the functions A and B are any functions of W, and similarly for the functions of V and U. The chart then consists of the following three parametric curves:

The W scale;	$x = A(W)$,	$y = B(W)$.
The V scale;	$x = C(V)$,	$y = D(V)$.
The U scale;	$x = E(U)$,	$y = L(U)$.

APPENDIX 6.

The equation of a bilineal family of curves is

$$M(W) - F(U) - G(U) \cdot H(V) = 0.$$

This equation can be put into the following form,

$$\begin{vmatrix} 0 & M(W) & 1 \\ 1 & -H(V) & 1 \\ G(U) & F(U) & 1 \\ \hline 1 + G(U) & 1 + G(U) & \end{vmatrix} = 0.$$

The chart then consists of the following curves:

The W scale	$x = 0,$	$y = M(W).$
The V scale	$x = 1,$	$y = -H(V).$
The U scale	$X = \dfrac{G(U)}{1 + G(U)}$	$y = \dfrac{F(U)}{1 + G(U)}$

The W and the V scales then are on parallel lines, on which the graduations are proportional to $M(W)$ and $H(V)$ respectively. In the case of a lineal family, one of the functions either $M(W)$ or $H(V)$ reduce to W or V respectively.

* * * * * *

Direct Current Power Transmission.—At the Winter convention of the A. I. E. E., Dr. C. H. WILLIS, B. D. BEDFORD, and Dr. F. R. ELDER presented a paper describing a new system for constant current, direct current transmission. This is probably the first time that such transmission has been accomplished in a commercial capacity. A circuit was installed at the research laboratory in Schenectady for the transmission of 150 K.W. of power. It operated at a maximum peak of 15,000 v. and 10 amp. In a larger installation in the works of the General Electric Company a connection is made to a 13,800 v., 60 cycle, three phase bus with a circuit for transmitting a constant direct current of 200 amp. at 15,000 v. This circuit includes 15,000 ft. of conductor and is connected back to the 13,800 v. bus after being inverted from direct to alternating current. High voltage constant-current direct current is produced by means of electronic tubes and vice versa. Before transformation of current from A.C. to D.C. condensers and reactors are so connected that constant current alternating current is obtained. Similarly, after transforming D.C. to A.C., reactors and condensers change the constant current alternating current into constant potential alternating current. This arrangement of condensers and reactors is known as a monocyclic network.

Features of the system have many advantages over the usual alternating current transmission in general use today. Power can be transmitted in either direction and there is control of the amount of power flow at all times. Being direct current, no wattles power is transmitted. A short circuit results in a reduction of power flow making for system reliability and less disturbance caused by lightning. The system cannot become out of phase or out of synchronism with the system feeding it or with the system receiving power.

R. H. O.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

DIRECTIONAL RADIO AS AN AID TO MARINE NAVIGATION.

There are a number of applications of radio which make for safety in marine navigation. These include intercommunication among ships, the broadcasting of information such as weather reports, time signals, iceberg warnings, distress signals, and direction determination. The principal system for direction determination is the radio direction finder, used in conjunction with radiobeacons as installed on many lightvessels and lighthouses. The radiobeacon broadcasts a coded signal at timed intervals, while the direction finder, when used aboard ships, indicates the direction to the source of the signal, and enables the navigator to get an azimuth bearing with respect to the beacon. With cross bearings on two or more radiobeacons, or point bearings on a single radiobeacon, the ship's position may be obtained.

This system was developed in coöperative experiments by the Lighthouse Service and the Bureau in 1920. Radiobeacons were installed on Ambrose Channel and Fire Island lightships and at Sea Girt, N. J., lighthouse, and a radio direction finder was installed on the lighthouse tender *Tulip*. These early experiments showed the great value of the system. Up to the present time the Lighthouse Service has installed approximately 106 radio beacons on our coasts, and there are a considerable number on foreign coasts. There are over 4,000 radio direction finders installed on ships throughout the world. Many instances are on record where the radio direction finder has been the means of locating a ship in distress and has thus made possible the saving of many lives.

There are three general classes of radio beacons, known as A, B, and C. They differ principally in their power rating. The class A radiobeacon is rated at 200 watts or over, the class B from 100 to 200 watts, and the class C below 100 watts. The class A beacon is used for long range work, such as the

* Communicated by the Director.

one installed on Nantucket Shoals lightship. This is the first beacon to be picked up by vessels approaching New York from the east. The class B beacon is the more common type and is used on lightships such as the Ambrose Channel lightship, as well as on outside coast stations. The class C beacon is usually used on inland waterways as, for instance, long Island Sound. The radiobeacon on Stratford Shoals lighthouse is an example of this type of beacon. Neighboring beacons usually operate in groups of three. The stations of each group operate on the same radio frequency, and each radiobeacon in the group is timed so that one transmits for one minute, a second for the second minute, and the third for the third minute. Each has a different coded characteristic for identification. Charts issued for the use of mariners by the U. S. Lighthouse Service give full details as to each radiobeacon, its location, class, characteristic signal, etc.

Some of the radiobeacon installations operate simultaneously with a sound signal through the air, so that a navigator may determine distance as well as direction. The difference in time between the arrival of the radiobeacon signal and the sound signal makes possible this distance determination. One radiobeacon is similarly synchronized with a submarine oscillator.

Rough distance determination may also be made for the purpose of avoiding collision with a lightship by steering so as to pass to one side of it. Successive radio bearings are taken, and these, with the intervening distance run, are used to ascertain the distance off from time to time.

Most of the direction finders in use on ships of the United States are of the simple rotating-coil type, with which a bearing is taken by listening for the point of minimum signal from the beacon, as the coil is rotated. A somewhat more complex type of direction finder recently developed at the Bureau is one in which the bearing indication is given by a zero-center pointer-type instrument. As the direction-finder coil is rotated the correct bearing is obtained when the pointer reads zero. This was developed primarily for airplanes, but would be useful also in marine service.

Tests have been made recently, with some degree of success, of a warning radiobeacon. This emits a low-power

signal, with a continuous high-low or warble note, and is intended to have an average range of about 10 miles. The tests indicate the probable value of such a signal on certain lightships, both to guide vessels and to protect the lightships.

Tests made on the Great Lakes by the Lighthouse Service have indicated the feasibility of the use by navigators of low-power radiobeacons on shipboard to obtain radio bearings on neighboring ships and thus avoid collisions.

Tests have been made in England of a system by which a ship can determine its position without the use of a direction finder. A transmitting coil antenna at the shore station is rotated at a known speed and a characteristic non-directional signal is sent when the minimum signal is being sent north. By the use of a stop watch and the ship's radio receiver a pilot is able to determine his azimuth position with respect to this beacon.

The use of ultra-high radio frequencies is developing rapidly. It may soon be possible to direct a radio beam (approximately 1/2 meter in wave length) from the upper structure of a ship and orient it forward in such a fashion that a highly directive receiver, underneath the transmitter and oriented to receive forward, will receive the signal only when some reflecting object exists in front of the ship.

INFRARED RADIATION FROM AN OTTO CYCLE ENGINE.

In T. N. B. No. 213 (January, 1935) it was stated that parts II and III of the paper on infrared radiation from an Otto Cycle engine would be published in a forthcoming number of *Industrial and Engineering Chemistry*. It has now been decided not to publish this material at this time.

PSYCHROMETRIC CHARTS FOR HIGH AND LOW PRESSURES.

A series of charts has been developed at the Bureau which facilitates the determination of humidity from the readings of dry- and wet-bulb thermometers. This determination is becoming of great importance with the rapidly increasing application of air conditioning to industrial processes.

Humidity charts and tables heretofore used have been strictly correct only at one air pressure, if at all. The present

charts are equally correct at air pressures encountered in stratosphere flights or in the deepest mines. While the pressure graduations on the charts run from that for 50,000 feet altitude to ten times normal atmospheric pressure, the charts can be used at any other pressure by either of two expedients.

Not only can the charts be used to evaluate relative humidity or pressure of water vapor from psychrometric data; they can be used also to determine the dewpoint, the saturation pressure of water, how to obtain a desired relative humidity by heating or cooling a given atmosphere, and the precision required in psychrometric measurements to obtain a desired precision in the result.

Four charts comprise this series, two being for use each with Fahrenheit and with centigrade thermometers. By thus dividing the temperature range, part being covered on each of two charts, interpolation can be practically eliminated for ordinary work. This makes the use of the charts simpler and more rapid. These charts have been published as Miscellaneous Publication M146, obtainable from the Superintendent of Documents, Government Printing Office, Washington, D. C., at 5 cents per copy.

IMPACT AND STATIC TENSILE PROPERTIES OF BOLTS.

Bolts are used in machines and structures to fasten together certain parts which cannot readily be made of one piece, or which must be removed for adjustment, cleaning, or repairs. In many cases these fastenings are subjected in service to static and to impact tensile loads. In designing a structure the engineer must know not only the greatest load which a bolt will sustain without failing, but also the work (force times distance) required to rupture the bolt. This is important because, under unusual circumstances, the bolted structure may be subjected either to steady or to impact loads greater than the working loads for which the structure was designed.

The resistance to static loads depends upon the tensile strength of the bolt with nut. The resistance to impact loads, however, depends upon the work required to rupture the bolt under suddenly applied loads. This "impact work" depends

not only upon the tensile strength but upon other factors, one of the most important of which is the amount of stretch between the head of the bolt and the nut when rupture occurs.

Many investigations have shown that for metals under either tensile or transverse loading the work required to rupture the specimen under loads applied slowly (the "static work") is not equal to the work required to rupture it under loads applied suddenly (the "impact work").

An investigation was made some time ago at the Bureau to determine the properties of bolts under impact tensile loading and also under static tensile loading. The results are given in RP763 in the February number of the *Journal of Research*. Three hundred and sixty specimens were tested, representing all the possible combinations of five different materials (chromium-nickel steel, cold rolled steel, monel metal, bronze, and brass); four different bolt diameters (3/8, 1/2, 5/8, and 3/4 inch); and three different forms of screw threads (American National coarse, American National fine, and Dardelet). These threads are often used for bolts, the U. S. Standard threads being almost the same as the American National coarse threads and the S. A. E. threads practically the same as the American National fine threads.

The bolts of different diameters were geometrically similar, the length between the head and the bearing face of the nut being five times the diameter, and the thread extending inward from the face of the nut for one diameter. In all cases the impact works for bolts having American National coarse threads were less than the impact works for bolts of the same size and material having American National fine threads. Except for the brass bolts and those cold-rolled steel bolts which showed brittle failures, the impact works for bolts having American National fine threads were approximately the same as the impact works for bolts of the same size and material having Dardelet threads. In all cases the impact works for bolts having Dardelet threads were much greater than the impact works for bolts of the same size and material having American National coarse threads.

The relations of the static works and the maximum static loads were similar to those for the impact works.

For bolts of the same size and having the same threads

the bolt efficiencies were approximately the same for all of the materials.

The results of this investigation will make it possible for engineers to use screw threads which will give the best results in service, and the public will benefit through increased safety and efficiency of machines and structures.

INFLUENCE OF OXIDE FILMS ON THE WEAR OF STEEL.

A few months ago the Bureau published the results of a study of the influence of oxide films on the wear of several plain carbon steels (*J. Research N. B. S.*, **13**, 267 (August 1934); RP708). It was shown that under given conditions of load and slip in metal-to-metal wear, the wear of carbon steels having a wide range of hardness was not very severe when tested in air and that a smooth filmed surface resulted. However, in a hydrogen atmosphere, but otherwise under the same conditions, carbon steels with higher hardness numbers (above 56 Rockwell C) wore relatively little, accompanied by the formation of very thin films, whereas steels of lower hardness suffered excessive wear and the worn surface was rough and showed no visible film.

The wear of stainless steels is now being studied. Preliminary results show that there is a similar change in character of wear when tests are made in hydrogen. A very noticeable difference, however, has been observed with a "ball-bearing type" stainless steel when tested in air. Under these conditions the stainless steel shows a transition from heavy wear with a rough film-free surface to relatively little wear with a smooth filmed surface as the hardness of the stainless steel increases from 45 Rockwell C to 62 Rockwell C (approximately). Apparently in the case of this stainless steel the surface oxide film is of such a nature as to permit the transition from rough to smooth wear in air, a transition which occurred with carbon steels only when the formation of surface oxide film was retarded by a surrounding atmosphere of hydrogen.

CORROSION RESISTANCE OF STAINLESS STEEL JOINTS.

Recent routine corrosion tests of jointed specimens of stainless steel (18–8) in the "salt spray" have given some

interesting data on the relative behavior of the stabilized and unstabilized steels. The tests were of 500 hours' duration in a "fog" of a 20 per cent. sodium chloride solution maintained at 35° C. "Joints" in the specimens were made by means of spot welding, gas welding and soft soldering, respectively.

Apparently neither spot welding nor soft soldering caused carbide precipitation in the structure of either the stabilized or the unstabilized material. Some grain boundary carbides were detected at the edge of gas welds in stabilized material but not any appreciable distance from the weld. In gas-welded unstabilized material, carbide precipitation at a considerable distance from the weld was formed.

On the whole, specimens of stabilized material were definitely superior to those of unstabilized material in their resistance to corrosion by the salt spray. This was especially true in specimens on which soft solder was used.

OXYGEN AND NITROGEN IN ANTIMONY CRYSTALS.

Recent investigations have established the fact that single metal crystals are far from having the uniform perfect lattice structure which one might postulate from theoretical considerations. Attempts have been made to correlate this irregularity in the crystal structure with various observed properties. It appears not unreasonable to suppose that if gases were present in a metallic crystal they might be associated to some extent with these irregularities in the crystal lattice structure. In a study of the thermal expansion of single antimony crystals which has been in progress at the Bureau for some time, variations in the temperature-expansion relationship were observed to occur on annealing the single crystal and it was supected that gaseous oxygen or nitrogen in the crystal might be responsible. However, analysis by the vacuum fusion for gases evolved on heating failed to reveal significant amounts of either oxygen or nitrogen. The small traces of gas which were detected could be accounted for on the basis of slight surface oxidation of the antimony.

RUSSIAN VISITOR STUDIES "GASES IN METALS."

In response to a request from the Embassy of the Union of Soviet Socialist Republics to the Department of State, per-

mission was granted to a technical representative of the Soviet Institute of Steel to spend several weeks in the metallurgical laboratories of the Bureau. Accordingly, A. M. Samarin, an instructor in metallurgy at the Steel Institute of Moscow, spent the month of December studying the methods recommended and used by the Bureau for determining those constituents of steels which are popularly, though, erroneously, termed "gases in steel." Such constituents are related, either in their origin or in their subsequent behavior upon heating, to the ordinary gaseous elements.

TRAFFIC SIGNALS.

The International Commission on Illumination has a committee on traffic signals, and a member of the Bureau's staff is the U. S. representative on this committee. For the purposes of the international committee an estimate has recently been made of the extent of use of luminous traffic signals in the United States, based upon statements of manufacturers as to their output. The estimates refer to January 1, 1934.

Reports from manufacturers of signal glasses show the following output:

Green	116,700
Amber	88,400
Red	141,700
Total	346,800

The output of red glasses is 21 per cent. higher than green, which can only be partly accounted for by the replacement of red for amber in the system of certain municipalities.

Reports from manufacturers of signal heads indicate that more than 29,000 intersections in the United States had been equipped. This is a lower limit, as the records are not complete.

Comparison of this figure with the output of signal glasses, without allowance for replacements, indicates an average of approximately 12 signal glasses per intersection. This is a reasonable ratio, as four one-way three-color signals would use exactly 12 glasses. A T-intersection using two colors would

have only 6, while four-way signals at each of four corners using three colors (as in Chicago) would involve 48 glasses.

Since the green glass is used in all systems, the number of sets of lenses may be based upon the green, which gives 4 sets of lenses per intersection, the exact number of four one-way signal heads.

The data received from manufacturers indicate that about 93 per cent. of the installations use three colors and about 7 per cent. use only two colors. The latter are largely in New York State and the Pacific Coast cities. The output of amber glasses is, however, 24 per cent. less than the green, which would indicate a much larger use of the two-color system.

LIGHTNING AND THE WASHINGTON MONUMENT.

When the Washington Monument was completed about 50 years ago it was provided with protection against lightning, but not until after it had been struck a number of times, and one of the stones cracked.

When the scaffolding was erected to the top of the monument last year for the purpose of cleaning it, an opportunity was presented for inspecting the lightning-protection equipment. (See Technical News Bulletin No. 212; December, 1934.) A member of the Bureau's staff was requested to do this.

The tip of the pyramid which constitutes the top of the monument is a block of aluminum weighing 100 ounces and nearly 9 inches high. It was surrounded by a gold-plated collar of copper studded with eight points or terminals. From each corner of the collar a copper rod ran down one edge of the pyramid, and these rods were connected by horizontal strips of copper laid between the courses of stone. Both rods and the horizontal strips carried copper points at intervals. These points were about 3 inches long, tapering from 1/4 in. in diameter at the base to about 1/16 in. at the outer end. The copper was gold-plated for protection against corrosion, and the pointed end was tipped with a piece of No. 20 platinum wire. There were approximately 200 of these.

The points at the peak of the pyramid showed abundant evidence of having been struck by lightning. Several had been fused at the tip, one carrying a distinct bead of fused

copper about 1/8 in. in diameter. The heat had corroded the surface somewhat and dissipated the gold, and some of the points had sagged. The tip of the aluminum was roughened and a globule of molten metal had run down one side and frozen.

The copper rods running down the edges of the pyramid were connected at several points through the stone to the interior steel framework supporting the elevator and this framework was loose. No damage had been done by lightning since this installation was made, although the monument had been frequently struck.

Upon recommendation of the Bureau's engineer, the joints in the rods were repaired and the points at the apex replaced by longer ones which extend higher than the aluminum, so that they can be expected to receive future strokes. All missing points on the rods and horizontal strips were replaced by gold-plated copper as in the original installation.

A measurement of the resistance between the collar at the apex and the steel framework inside was made after the repairs and found to be less than one-thousandth ohm.

HINGES FOR REINFORCED CONCRETE STRUCTURES.

The utility of hinges or articulations for reinforce-concrete arches and frames has been recognized for many years. Articulations in these structures fix the position of the line of thrust at definite points in the structure, thereby reducing the uncertainties in analyses of stresses. Stresses caused by movements in the foundations and those produced by shrinkage, plastic flow, rib shortening, and temperature variations can be reduced by the use of hinges, and in the case of the three-hinged arch, almost entirely eliminated.

The type of hinge which was first designed and used by Augustin Mesnager, a French scientist and engineer, appears to be well suited for use in reinforced-concrete structures. These hinges are made by leaving a short gap in the concrete of the member and crossing the reinforcing bars at the gap. Thus the intradosal bars on one side of the gap become the extradosal bars on the other side. This type of hinge is known to offer only a small resistance to rotation or flexure and yet has a considerable resistance to thrust and shear. Before

extensive use, however, it seemed desirable to obtain additional experimental data on these properties. At the suggestion of representatives of the Bureau of Yards and Docks, Navy Department, seven specimens with hinges of the Mesnager type were tested at the National Bureau of Standards.

The specimens, which were designed by Lieut. Comdr. Ben Moreell, Bureau of Yards and Docks, resembled a crown hinge with part of the adjacent barrel of a barrel-shaped arch. They were tested under conditions which gave information on both the stiffness and the strength of the hinges when subjected to compressive, shearing, and rotational deformations. The results of the tests indicate that hinges of the Mesnager type may be designed to provide a wide range in strength and stiffness. A complete report on the investigation will be published in the January-February issue of the *Journal of the American Concrete Institute*.

TENSION TESTS OF FIRE BRICK.

The nature of refractory bricks is such as to have discouraged much study of their tensile properties in the past. However, the advent of the Tuckerman optical strain gage has eliminated many of the difficulties, so that strain measurements of materials as brittle as fire-clay brick may now be made accurately. The Bureau has, therefore, undertaken a study of the strength, Young's modulus of elasticity, and maximum strain in tension of 18 commercial brands of fire-clay brick. These brands of brick have been chosen so as to include not only the different processes of manufacture (hand-made, dry press and stiff mud), but also the range of silica ordinarily found in fire brick.

An apparatus was constructed so as to permit tests to be made both at ordinary and elevated temperatures. The load is gradually applied to the specimens through a simple lever system by means of No. 12 lead shot. Strain measurements are taken from two gages placed opposite one another on the specimen.

Three specimens are machined from each brick, one specimen is cut crosswise and two are cut lengthwise to the brick. The specimens are machined spool shaped and the one cut

crosswise to the brick is suitable for a 2-inch gage length and those cut lengthwise are suitable for a 3-inch gage length. The finished specimens have a circular cross section, 1.50 in.^{2} in area.

Some results are available on each of 18 brands of brick. Nine specimens representing three specimens from each of three bricks of one brand have been tested. The range in values for the 18 brands is as follows: modulus of elasticity from 209,000 to 7,600,000 lb./in.^{2}, the tensile strength from 40 to 920 lb./in.^{2}, and the strain from 0.0052 to 0.0316 per cent. Comparing the values obtained for the crosswise and the lengthwise specimens shows that the modulus of elasticity was greater for the crosswise specimens in 11 brands, less in 6, and equal in 1. The strength of the crosswise specimens was less than the lengthwise specimens in 16 brands. Crosswise specimens from a single brick were found to be as much as 65 per cent. higher in modulus of elasticity in comparison with lengthwise specimens. The following values obtained on two brands show the possible uniformity and non-uniformity of tensile properties which may occur. First brand, modulus of elasticity and strength lengthwise 1,225,000 and 300 lb./in.^{2}, respectively; modulus of elasticity and strength, crosswise 1,220,000 and 260 lb./in.^{2}, respectively. Second brand, modulus of elasticity and strength lengthwise, 1,530,000 and 355 lb./in.^{2}, respectively; crosswise 2,530,000 and 350 lb./in.^{2}, respectively.

CALIBRATION OF WAGNER TURBIDIMETER.

Twenty-seven laboratories coöperated with the cement reference laboratory at the Bureau in a study of a suggested method of calibration of the Wagner turbidimeter, an instrument now used by many laboratories in determining the fineness of portland cement. It was believed that the new method would bring about better agreement among laboratories than was secured through the earlier method.

Four samples of cement were used. One sample was selected as the standard for calibration, its specific surface and No. 325 sieve values being given. The three remaining samples were unknowns to test the efficiency of the proposed method. Results by the old method were reported by 24

laboratories, while 27 reported results using the new method. The range in results by the new method was much smaller than existed in the results by the older method. Also, by the new method the standard deviation and the probable error were less than one-half of the respective values for the old method. The new calibration method forms part of the recently adopted ASTM tentative method of test for fineness of portland cement by means of the Wagner turbidimeter, C115–34T.

It was found that the specific surface of the standard sample decreased rapidly after exposure to the air. Therefore, the sample prepared by the Bureau for this calibration, Standard Sample No. 114, is now "glass-sealed" in small vials. Each sample consists of three vials, each vial containing sufficient cement for three calibrations, including the No. 325 sieve test by the wet method.

There has been some occasional discussion as to the probable magnitude of the error incident to the use of the No. 325 sieve in the turbidimeter determination. (One gram is tested on a small sieve by the wash method.) This question is answered by the following study of the values reported by the 27 laboratories above mentioned.

Nature of data.	Sample number.		
	23678.	23680.	23934.
	per cent.	per cent.	per cent.
Average amount passing	88.4	94.9	89.3
Standard deviation	0.8	0.5	0.9
Probable error	0.6	0.3	0.6
Surface area equivalent to the above probable error in sieving	11 $cm.^2/g.$	9 $cm.^2/g.$	13 $cm.^2/g.$

STANDARDS FOR GAS SERVICE.

A revision of the Bureau's circular on "Standards for Gas Service" was released last month. The purpose of the publication is to supply the technical information needed by anyone concerned with the basis of charging for gas or with the conditions which will result in satisfactory service.

With the exception of coal, city gas is the principal source of heat energy for use in American homes, and it is as a supply

of energy rather than as a material that gas is discussed in the circular. It is of no concern to the user how many cubic feet of gas he can buy for a dollar; the only things that matter are the amount of energy received and the maintenance of conditions which will make it easy to control the energy in use. Fixing the price of gas per cubic foot results in many complications and often in unsatisfactory or wasteful conditions which can be avoided when the price per unit of energy is established instead, as it is in Great Britain and Japan, and in the State of Colorado and the City of Chicago. This is particularly important in the case of natural gas, for which a minimum standard of heating value, such as is usually established for manufactured gas, is unsuitable. Natural gas at present constitutes the major portion of the nation's supply, and the conditions under which it is produced, distributed, and sold deserve much more attention from the public than they have received.

In addition to the heating-value of gas, the circular discusses the maintenance of satisfactory pressures, the composition of the gas, the adjustment of appliances, the accuracy and testing of meters and the adjustment of bills when meters are found in error, and the extension of the distributing system to supply new customers. Recommendations are made in relation to each of these topics and the reasons for them are fully explained.

A summary is given of all existing State regulations relating to gas, so arranged that it is easy to compare the rules on any subject. Another summary indicates what gas companies, themselves, regard as good practice. There is also a description of the properties, sources, and methods of manufacture of the numerous kinds of gas which go to make up city supplies.

The Circular, C405, can be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C., at 20 cents per copy.

REPORTS OF NATIONAL HYDRAULIC LABORATORY.

Current hydraulic laboratory research in the United States. Report no. III–1 (January 1, 1935). Mimeographed. Free on application to National Bureau of Standards, Washington, D. C.

THE FRANKLIN INSTITUTE.

STATED MONTHLY MEETING, FEBRUARY 20, 1935.

The regular monthly meeting of The Franklin Institute was called to order by Mr. W. Chattin Wetherill, Vice-President, who presided in the absence of the President, Mr. Hayward.

For compelling reasons the business to be brought before the meeting had to be withheld. It will be taken up at the March meeting of the Institute.

The speaker of the evening, Mr. L. K. Sillcox was introduced by the presiding officer. Mr. Sillcox addressed the meeting on "The End of an Era." The lecture was well attended and well received. Mr. Sillcox gave an exceedingly illuminating talk on the subject of railroads. The meeting adjourned with a rising vote of thanks to the lecturer for his delightful presentation of a very timely subject.

HOWARD MCCLENAHAN,
Secretary.

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of Stated Meeting held Wednesday, February 13, 1935)

HALL OF THE COMMITTEE,
PHILADELPHIA, FEBRUARY 13, 1935.

MR. CHARLES D. GALLOWAY *in the Chair.*

The following reports were presented for final action:

No. 2995 } The Standing Committee on The Franklin Medal presented
No. 2996 } its report for final action making the following recommendations:

"That the recipients of the two Franklin Medals to be awarded in 1935 be:

"ALBERT EINSTEIN, theoretical physicist and mathematician, 'In recognition of his contributions of fundamental importance to theoretical physics, especially his work on Relativity and the Photo-electric Effect';

"And SIR JOHN AMBROSE FLEMING, electrical engineer, 'In recognition of his many contributions to the improvement of the art of communication, and especially the invention of the thermionic valve which bears his name.'"

No. 2998: Literature.

This report recommended the award of the Louis Edward Levy Medal to Dr. H. L. Hazen, of the Massachusetts Institute of Technology, for his two papers published in the September, 1934, issue of the Journal of the Institute, and the November, 1934, issue, entitled respectively "Theory of Servo-Mechanisms" and "Design and Test of a High Performance Servo-Mechanism."

The following reports were presented for first reading:

No. 2989: Automatic Spooler.
No. 2992: Radio Antenna of the Rhombic Type.
No. 3000: Thyrite.
No. 3001: Clark Medal.

GEO. A. HOADLEY,
Secretary to Committee.

MEMBERSHIP NOTES.

ELECTIONS TO MEMBERSHIP.

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MR. HARRY C. HART, Electrical Engineer, Charles S. Leopold, Consulting Engineer, Philadelphia, Pa. For mailing: Penllyn, Pa.
MR. HENRY D. MACONACHY, Artist, Philadelphia, Pa.
DR. ALEXANDER RANDALL, Associate Professor of Surgery, Hospital of the University of Pennsylvania, Philadelphia, Pa.

NON-RESIDENT.

MR. LEONARD V. NEWTON, Automotive Engineer, Byllesby Engineering and Management Corporation, Chicago, Illinois.

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Mr. Thomas L. Scatchard, 2260 North Broad Street, Philadelphia, Pa.
Mr. Harry R. Van Deventer, 34 East Fifty-first Street, New York City, N. Y.
Mr. John J. Wolf, 957 North Fifth Street, Philadelphia, Pa.

NECROLOGY.

Mrs. John S. Pepper, Jenkintown, Pa.

LIBRARY NOTES

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BOOK REVIEWS.

ATOMIC STRUCTURE AND SPECTRAL LINES, by Arnold Sommerfeld, Professor of Theoretical Physics at the University of Munich, translated from the fifth German edition by Henry L. Brose, M.A., D.Phil., D.Sc. 675 pages, tables, illustrations. 14.5 × 23 cms. New York, E. P. Dutton and Company, Inc. Price $10.80.

The mere statement that a book has reached the fifth edition should serve as an excellent recommendation. The gradual growth of such a work throughout a series of editions is evidenced by the appearance of two meaningful words on the title page: Volume One. So great has been the expansion of the subject matter, there is sufficient for a second volume. Last, but not least, we are speaking about the English Translation from the original German—mute evidence of its worthwhileness.

In this Fifth Edition of Atomic Structure and Spectral Lines, the author, himself one of the original developers of modern atomic physics, has undertaken a considerable degree of revision. The present volume now contains the older quantum theory while the more advanced theories as embodied in "wave mechanics," are reserved for the forthcoming second volume. Not only are the basic experimental facts included but with them such orbital ideas as are required for introducing the quantum numbers and for serving as models for the wave-mechanical calculations. The first seven chapters have been abbreviated somewhat. The methods involved in Hamiltonian mechanics have been rescued from the Appendix and placed in the text proper. Chapter Eight which treats of multiplet structures, has been extended by the inclusion of the model of the spinning electron and of Pauli's Principle. Chapter Nine on Band Spectra has been kept short and contains only what is essential for wave-mechanics.

It does not seem fair to dismiss the first seven chapters with the single sentence in the previous paragraph. As is customary, the primary chapter consists of Introductory Facts. Then, in keeping with the elemental beginning, Chapter Two covers the hydrogen spectrum. The Natural System of Elements probably will be voted the most impressive by those readers whose interest is general.

X-Ray Spectra logically follow that of classification of the elements. Chapters Five and Six deal with the Theory of Fine Structure and Polarization and Intensity of Spectral Lines respectively. A general discussion of Series Laws constitutes the makeup of the Seventh.

The importance of the translator in a work of this type certainly cannot be ignored. As in all translations of excellence, the original text has not been transcribed too literally and the author has sanctioned such modifications as have been added at the discretion of the translator. An addendum by Professor Brose serves to bring the reader up to date on the more recent developments on atomic and sub-atomic physics. The Mathematical Appendix is transferred from the original text and is intended to serve those who are more advanced.

T. K. CLEVELAND

HANDBOOK OF CHEMISTRY. Compiled and Edited by Norbert Adolph Lange, Ph.D., assisted by Gordon M. Forker, B.S. (Chem. Eng.), with an appendix of mathematical tables and formulas by Richard Stevens Burington, Ph.D., 1265 pages plus mathematical supplement of 248 pages and index, 29 pages. 13.4 × 19.7 cms. Sandusky, Ohio, Handbook Publishers, Inc., 1934. Price $6.00.

Chemists everywhere should welcome this excellent new handbook. While designed particularly for chemists it has many features commending it to physicists, mineralogists, engineers, dieticians, manufacturers and others.

The book is too big and heavy for pocket use. It is attractively printed and Fabricoid bound but there is some question as to how long the binding will stand up under the heavy usage for which such a book should be designed. The tables are printed in a modern type clearer than usually found, with generic names in bold face. The pages are relatively large and tables usually not crowded, an innovation to eye-strained scientists.

It is impossible to give any adequate comprehension of the contents in so brief a review. Practically all the tables that chemists have learned to look for in other handbooks are here though frequently under different and sometimes improved arrangements. The tables are simple, however, and only a few references to them are needed to make their use perfectly familiar.

A few tables not ordinarily looked for in chemical handbooks may be cited at random: Hazardous chemicals, changes in atomic weights from 1894 to 1933, effective radii of atomic ions, properties of minerals, radio detector minerals, names and formulas of organic radicals, numerical prefixes, separate tables of constants of alkaloids, of glucosides, physical and chemical properties of resins, the vitamins, numerous tables relating to milk and ice cream, several tables of interest to water chemists, of composition and heating values of representative coals, excellent tables of composition and properties of alloys, pipes, valves and fittings, extended tables relating to ceramics, compounds useful for determining melting points with the microscope, antifreeze solutions, properties of refrigerants, humidity and dew point tables. There are extended tables on barometry and barometric corrections and on values of gravity at various stations. Other useful tables give the common physical chemistry equations and list the chemical journals.

The practical man will appreciate that many tables name names and cite the manufacturer as in connection with tables of alloys.

There is less opportunity for innovation in the mathematical section. The usual things are there. Some of the less common things are seven place logarithms of numbers 10,000 to 12,000, decimal equivalents of common fractions, interest, discount and annuity tables, American experience mortality tables and the probability and elliptic integrals.

It is of interest to point out that tables of molecular weights, gravimetric factors and so on are compounded with the 1933 International Atomic Weights. The book is modern in every sense and will surely gain wide popularity.

LESLIE R. BACON.

HIGH-FREQUENCY MEASUREMENTS, by August Hund, first edition, 491 pages, illustrations, 15.5 × 23.5 cms. New York and London, McGraw-Hill Book Company, Inc., 1933. Price $5.00.

This book, treating on a highly technical subject, is an up-to-date work on high frequency phenomenon applied to measurements. Measurements, in some respects, at high frequencies do not differ essentially from low frequencies, while in other respects new methods are necessary. Chapter I on Fundamental Relations and Circuit Properties, explains the differences and the basic considerations necessary for high frequency measurements. The apparatus necessary for establishing high frequencies, other useful laboratory apparatus and systems for measuring high frequency, in general, are described in Chapters II and III. The following sections of the book are devoted to various determinations, each section treating on specified subjects such as frequency determination, effective resistance, high frequency power and losses, etc. Every measurement of value is taken up and treated in a thorough and practical manner. At the end of the book a part is devoted to miscellaneous measurements and data in which there are notes on special indicators and information helpful in procedures where a method is employed in one case which is not suitable for another, since the order of magnitude of the quantity to be determined and the range of frequency play an important part.

This book is a business-like, practical treatise by a master of the subject. Perusal of its contents should prove of great benefit to those qualified by education and experience in the subject. It is valuable as a text and reference book to those whose occupation or inclination carries them into experimental or inventive fields as well as practical applications.

R. H. OPPERMANN.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

Report No. 489. Air Conditions Close to the Ground and the Effect on Airplane Landings, by F. L. Thompson, W. C. Peck, and A. P. Beard. 15 pages, illustrations, 23 × 29 cms. Washington, Superintendent of Documents, 1934. Price ten cents.

This paper reports an investigation undertaken to determine the feasibility of making glide landings in gusty air. Wind velocities were measured at several stations between the ground and a height of 51 feet, and flight tests were made to determine the actual influence of gusts on an airplane gliding close to the ground. The airplane used for the flight tests was equipped with a landing gear of unusually long travel so that glide landings with the elevator fixed could be

made under favorable air conditions. In very gusty air the glides with fixed elevator were terminated at a safe altitude without actual landings.

The results of the wind measurements indicate an average increase in velocity with height in accordance with the expression $\frac{V}{V_1} = \left(\frac{h}{h_1}\right)^{1/7}$. Maximum variations in the horizontal components of wind velocity were found to be of the order of ± 4 miles per hour without perceptible dependence on the average velocity or height, while maximum variations in vertical components were of the same order at the higher elevations, decreasing with height but with no perceptible dependence on wind velocity. Unchecked glide landings in gusty air with the conventional airplane were found to be unduly hazardous. The hazard would tend to be reduced, however, by the addition of a high-lift device that extends the lift curve without modifying the lift characteristics in the normal range of angle of attack.

Report No. 493. The Physical Effects of Detonation in a Closed Cylindrical Chamber, by C. S. Draper. 21 pages, tables, illustrations, 23 × 29 cms. Washington, Superintendent of Documents, 1934. Price ten cents.

Detonation in the internal-combustion engine is studied as a physical process. It is shown that detonation is accompanied by pressure waves within the cylinder charge.

Sound theory is applied to the calculation of resonant pressure-wave frequencies.

Apparatus is described for direct measurement of pressure-wave frequencies.

Frequencies determined from two engines of different cylinder sizes are shown to agree with the values calculated from sound theory.

An outline of the theoretically possible modes of vibration in a right circular cylinder with flat ends is included.

An appendix by John P. Elting gives a method of calculating pressure in the sound wave following detonation.

Report No. 494. A Flight Investigation of the Lateral Control Characteristics of Short Wide Ailerons and Various Spoilers with Different Amounts of Wing Dihedral, by Fred E. Weick, Hartley A. Soule and Melvin N. Gough. 16 pages, illustrations, tables, 23 × 29 cms. Washington, Superintendent of Documents, 1934. Price ten cents.

Flight tests were made to determine the lateral control characteristics of short wide ailerons and spoilers, as a consequence of the promise shown in wind-tunnel tests by these devices as means of obtaining lateral control, particularly at angles of attack above the stall. Several forms of spoilers, front-hinge, rear-hinge, plain retractable, and saw-tooth retractable were tested alone and in combination with the ailerons. The tests were made with several different amounts of wing dihedral so that the effect of the yawing moments of the different lateral control combinations, which varied from large negative to large positive values, could be evaluated. In conjunction with the tests, observations were made to throw some light on the feasibility of operating the airplane with two controls instead of the present three.

The short wide ailerons gave no control above the stall. The spoilers gave

some control in the stalled flying range, although the tests showed that for safe operation in this range lateral stability as well as lateral control is required. The spoilers were unsatisfactory, however, because of a lag between the movement of the control surface and the response of the airplane. A combination of the ailerons and spoilers appears to offer possibility for further development, the spoilers giving control beyond the stall and the ailerons by their immediate action covering up the lag of the spoilers in normal flight range. The importance of yawing action of a lateral control system was found to increase considerably with increasing dihedral. Large positive yawing moments, though an advantage above the stall, may be undesirable in the normal flight range because they tend to depress the nose of the airplane while rolling into steeply banked turns.

Two-control operation of the airplane in flight was found to be feasible with either the rudder and elevator combination or the aileron and elevator combination, but it limited the maneuverability and would therefore be desirable only with certain types of airplanes. The landing characteristics of an airplane with two controls have not been evaluated.

Report No. 499. Wind-Tunnel Research Comparing Lateral Control Devices, Particularly at High Angles of Attack. XII—Upper-Surface Ailerons on Wings with Split Flaps, by Fred E. Weick and Carl J. Wenzinger. 17 pages, tables, 23 × 29 cms. Washington, Superintendent of Documents, 1934. Price ten cents.

This report covers the twelfth of a series of systematic tests being conducted by the National Advisory Committee for Aeronautics to compare different lateral control devices with particular reference to their effectiveness at high angles of attack. The present tests were made in the 7- by 10-foot wind tunnel with two sizes of upper-surface ailerons on rectangular Clark Y wing models equipped with full-span split flaps. The upper-surface ailerons were formed from the upper portions of the split trailing edges of the wings. The tests showed the effect of the upper-surface ailerons and of the split flaps on the general performance characteristics of the wings, and on the lateral controllability and stability characteristics. The results are compared with those for plain wings with ordinary ailerons of similar sizes.

With flaps neutral, the upper-surface ailerons with up-only movement gave rolling moments at angles of attack below the stall that were reasonably close to an assumed satisfactory value. The yawing moments (wind axes) were positive (favorable) with large aileron deflections but, at all except the lowest angles of attack, they were slightly negative (adverse) with small deflections. The control forces were much greater than those of ordinary ailerons of similar sizes having conventional movement. With the flaps deflected for maximum lift, the upper-surface ailerons gave control moments considerably below the value assumed to be satisfactory. The magnitudes of the positive (favorable) yawing moments were smaller than those with flaps neutral and negative (adverse) ones occurred with small aileron deflections at all angles of attack. Above the stall, flaps neutral or deflected, both sizes of upper-surface ailerons indicated poor control.

The autorotational characteristics of the wings with the flaps deflected were somewhat less favorable than with the flaps retracted.

Report No. 500. The Influence of Tip Shape on the Wing Load Distribution as Determined by Flight Tests, by Richard V. Rhode. 25 pages, tables, illustrations, 23 × 29 cms. Washington, Superintendent of Documents, 1934. Price ten cents.

Pressure measurements were made in flight on the right upper wing of an M-3 airplane. The effects of tip plan form, washout, and transverse camber were investigated with eight tip forms in unyawed conditions throughout the range of positive lift coefficients from zero lift to the stall.

The principal conclusion is that the tip plan form does not influence the span distribution of the coefficients of normal force and moment. It is shown inferentially that temperature, humidity, and the aging of the wood and fabric wing structure used on the M-3 airplane have an appreciable influence on the load distribution.

Report No. 502. Scale Effect on Clark Y Airfoil Characteristics from N. A. C. A. Full-Scale Wind-Tunnel Tests, by Abe Silverstein, 15 pages, tables, illustrations, 23 × 29 cms. Washington, Superintendent of Documents, 1934. Price ten cents.

Tests were conducted in the N. A. C. A. full-scale wind tunnel to determine the aerodynamic characteristics of the Clark Y airfoil over a large range of Reynolds Numbers. Three airfoils of aspect ratio 6 and with 4-, 6-, and 8-foot chords were tested at velocities between 25 and 118 miles per hour, and the characteristics were obtained for Reynolds Numbers (based on the airfoil chord) in the range between 1,000,000 and 9,000,000 at the low angles of attack, and between 1,000,000 and 6,000,000 at maximum lift. With increasing Reynolds Number the airfoil characteristics are affected in the following manner: The drag at zero lift decreases, the maximum lift increases, the slope of the lift curve increases, the angle of zero lift occurs at smaller negative angles, and the pitching moment at zero lift does not change appreciably.

The Clark Y airfoil characteristics obtained from the tests in the full-scale tunnel are compared with those from the variable-density and the propeller-research tunnels, and with the theoretical values. An analysis of the comparative experimental data indicates that the air stream of the full-scale tunnel has a relatively low turbulence. This inference is substantiated by the close agreement obtained between the characteristics of airplanes measured in the full-scale tunnel and those from flight tests, and by sphere drag measurements that show the tunnel has a turbulence similar to free air. It is therefore believed that the effects of turbulence on the characteristics of an airfoil tested in the full-scale tunnel are small, and may be neglected in applying the data to design.

Report No. 503. The Effect of Spray Strips on the Take-Off Performance of a Model of a Flying-Boat Hull, by Starr Truscott. 19 pages, illustrations, 23 × 29 cms. Washington, Superintendent of Documents, 1934. Price ten cents.

The effect on the take-off performance of a model of the hull of a typical flying boat—the Navy PH-1—of fitting spray strips of four different widths, each at three different angles, was determined by model tests in the N. A. C. A. Tank. Spray strips of widths up to 3 percent of the beam improve the general performance

at speeds near the hump and reduce the spray thrown. A downward angle of 30° to 45° in the neighborhood of the step seems most favorable for the reduction of the spray. The spray strips have a large effect in reducing the trimming moments at speeds near the hump speed, but have little effect on them at high speeds.

RESONANCE RADIATION AND EXCITED ATOMS, by Allan C. G. Mitchell, Ph.D., and Mark W. Zemansky, Ph.D. 338 pages, illustrations, tables, 14 × 22 cms. New York, The Macmillan Company. Cambridge, University Press, 1934. Price $5.00.

After the usual run of books dealing with the general subject of atomic and sub-atomic physics, it is somewhat of a relief and a real pleasure to pick up a work which is more or less confined to one particular type of phenomena. Resonance radiation has not enjoyed the degree of attention that has been lavished upon numerous other physical manifestations since the turn of the century. The authors, recognizing that "no comprehensive account of the theories, experiments and interpretations connected with resonance radiation has up to the present existed" have set out to remedy such a condition and have succeeded admirably.

Although the book naturally will be historical, at least in part, Professors Mitchell and Zemansky have sought to maintain more of a critical attitude toward the whole subject. Such an approach is commendable and future work on "Resonance Radiation and Excited Atoms" should benefit considerably thereby. In accordance with this attitude, special attention has been paid to the principles and limitations of various methods of studying resonance radiation, while the existing discrepancies and outstanding problems yet to be solved have been critically discussed.

The subject matter is arranged under five chapter headings and each chapter is broken down into a number of sub-divisions. The usual and quite necessary introductory section comprises chapter one. A consideration of the "Physical and Chemical Effects Connected with Resonance Radiation" is relatively brief, indicating a paucity of data and a correspondingly promising field for research. Chapter III deals with absorption lines and measurements of the lifetime of the resonance state. The most important group of phenomena seemingly are the "collision processes involving excited atoms." Under this heading, the several types of line "broadening" are discussed as well as the observed facts and the theory in connection with quenching. A consideration of the polarization of resonance radiation comprises the fifth and last chapter. The Appendix contains a number of mathematical treatments that are supplementary to the main text.

T. K. CLEVELAND.

STEAM, AIR, AND GAS POWER, by William H. Severns, M.S., and Howard E. Degler, M.E., M.S., second edition, 480 pages, illustrations, tables, 15.5 × 23.5 cms. New York, John Wiley & Sons, Inc., London, Chapman & Hall, Ltd., 1933. Price $4.00.

An elementary text involving mathematical calculations of the simplest order. Intended for use in college courses dealing with heat engineering where only a limited amount of work in the subject can be included, this book describes

clearly and briefly the theory of representative equipment and the equipment itself.

The book begins with a brief review of the necessary subjects of physics, then a very good treatment of the principles of thermodynamics is given. This together with chapters on steam and steam calorimetry, and fuels form a basis for a detailed explanation of the various parts of a steam power plant including steam generators, feedwater treatment, draft apparatus, steam engines and turbines. Following this there is a chapter on steam condensing equipment. The theory and operation of other apparatus in a power plant is next explained. This includes pumps of various kinds, air compressors and engines. The concluding chapter deals with internal combustion engines, making clear the cycles of operation.

Aside from its extreme clarity, which alone makes it a valuable text, this book has other features that contribute toward assistance of the student in grasping the subject matter. An examination of the problems at the end of each chapter will reveal that they were made up with care and forethought. The index of subjects is also of great assistance as a reference.

R. H. OPPERMANN.

PRACTICAL FORMS IN EXPOSITION, A MANUAL DESIGNED TO ASSIST TECHNICAL STUDENTS WITH PAPERS, LETTERS, REPORTS AND READING, by Harlow C. Richardson, Luther N. Becklund, Ledru O. Guthrie, Clifford I. Haga, 429 pages, 16 × 24 cms. New York, The Macmillan Company, 1934. Price $2.00.

Writing correctly, for the technical man, is becoming increasingly important. To be able to give technical descriptions, definitions and to describe processes clearly and accurately is an invaluable aid and an absolute necessity in imparting knowledge.

This unusual book fills a vacant space in the knowledge storeroom of tools of many engineers. It begins with an introductory analysis of the language needs of engineers and discusses a technical man's reading—why, how and what to read. Those practicing engineers who are engaged in more or less active pursuits, who do not have the time or the inclination for reading, especially should read this part for it forcefully and clearly brings out the rewards available to those who use literature.

Upon this beginning the following chapters are founded. Six types of exposition are treated upon including process articles, making relationships visible and recommendation reports or analyzing the points for and against a plan. Of particular interest should be part three of the book on combinations of units of technical writing into long technical reports and business letters. This covers method, organization and layout more fully than is common in a textbook.

While the book is primarily a textbook for use in technical colleges, it is undoubtedly a valuable work to a great number of graduates. Its completeness in details, which are admirably illustrated, and its rather scientific approach make it appealing to the technically trained mind.

R. H. OPPERMANN.

LIFE AND EXPERIENCES OF A BENGALI CHEMIST, PRAFULLA CHANDRA RÂY. 557 pages, plates, 15 × 22 cms. Calcutta, Chuckerverty, Chatterjee and Company, 1932.

To us in America, India seems so remote and out of reach. It is not just across the Atlantic as are England, France and Germany, nor is it just beyond the Pacific as are China and Japan. Frankly, we younger chemists did not associate India and chemistry until the theories of Ghosh were encountered during our struggles with Physical Chemistry, yet full of growing pains. Older chemists, of course, were well acquainted with the work on new inorganic compounds by the author, Prafulla Chandra Rây.

Therefore, to turn back the cover from "Life and Experiences of a Bengali Chemist" is like drawing a curtain aside from a niche one scarcely knew existed. The author truthfully calls the first section of his book An Autobiography. So it is, but it is also a history of the development of Indian chemistry, since the two are inseparable. With many writers this entire first part of the volume would be played up for its romantic value. But not so with a chemist and realist such as P. C. Rây. He made of it an epic. His struggle against adversity has never ceased, nor has it been far from fruitless. In the twilight of his career any retrospection that may occupy his yet too few leisure moments must be a source of immense gratification in the knowledge of a pinnacle gained, an ambition fulfilled.

Although the author writes like a "Westerner" and often startles the reader with some unexpected word or phrase that might be classified as colloquialisms, he nevertheless is intensely patriotic and loyal to his race. The whole picture is presented from the standpoint of a highly intelligent native son of India. The statements seem singularly free from bias. Not only does he unhesitatingly point out the attendant evils of British rule in India but hastens to deplore the proverbial indolence of his people which also is partially responsible for their unfortunate condition.

Following his autobiographical history of Indian chemistry the author turns his attention to the Educational, Industrial, Economic and Social aspects of India in general and the Bengalis in particular. No longer does the reader look through the eyes of a chemist but rather those of the educator, the political economist and the socialist. If only the rulers and the ruled alike would heed his words: the former to help the latter and the latter help themselves. Though the barriers seem insurmountable, Sir Prafulla Chandra Rây points the way. He, like his compatriot, Mahatma Ghandi, has his peoples' welfare deeply at heart.

T. K. CLEVELAND.

PHYSICA, vol. II, no. 1, January 1935. The Hague, Martinus Nijhoff, 1935. Subscription 25 guilders, ten numbers yearly.

The first issue of the second volume of Physica has recently come from the press. The number contains ten articles covering problems relating to x-rays, compressibility of helium gas, photocells, a new theorem in operational calculus, etc. Seven of the papers are in English and three are in German.

The volume just completed contains 136 original contributions in all branches of physics, in three languages, by prominent Dutch physicists. There are over 1200 pages of text and many figures and plates.

R.

METEOROLOGICAL OFFICE, AIR MINISTRY. AVERAGES OF BRIGHT SUNSHINE FOR THE BRITISH ISLES FOR PERIODS ENDING 1930. 41 pages, 15.5 × 24.5 cms. London, His Majesty's Stationery Office, 1934. Price 1s, postage extra.

This work gives average monthly totals, daily means and percentages of possible duration of sunshine for all stations having ten years or more of observations in the period 1901–1930. The average and percentage number of days in each month with sunshine within stated limits of duration for eighteen selected stations are also recorded. One hundred and seventy-two stations are represented in this report of which thirty-one are in Scotland and nine in Ireland. The records for most stations cover a period of twenty years or more.

The data show that the average annual duration of recorded sunshine varies from over 1800 hours in the Channel Isles and on the south coast of England to under 1100 hours in the Shetlands and in certain industrial areas where heavy smoke pollution occurs. At all stations May or June is the sunniest month, and December or January the dullest.

R.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

Report No. 504, On the Theory of Laminar Boundary Layers Involving Separation, by Th. von Karman and C. B. Millikan, 22 pages, charts, 23 × 29 cms. Washington, Superintendent of Documents, 1934. Price ten cents.

The paper presents a mathematical discussion of the laminar boundary layer, which was developed with a view of facilitating the investigation of those boundary layers in particular for which the phenomenon of separation occurs. The treatment starts with a slight modification of the form of the boundary layer equation first published by von Mises. Two approximate solutions of this equation are found, one of which is exact at the outer edge of the boundary layer while the other is exact at the wall. The final solution is obtained by joining these two solutions at the inflection points of the velocity profiles. The final solution is given in terms of a series of universal functions for a fairly broad class of potential velocity distributions outside of the boundary layer. Detailed calculations of the boundary layer characteristics are worked out for the case in which the potential velocity is a linear function of the distance from the upstream stagnation point. Finally the complete separation point characteristics are determined for the boundary layer associated with a potential velocity distribution made up of two linear functions of the distance from the stagnation point. It appears that extensions of the detailed calculations to more complex potential flows can be fairly easily carried out by using the explicit formulas given in the paper.

STRUCTURAL DESIGN IN STEEL, by Thomas Clark Shedd, Professor of Structural Engineering, University of Illinois. 560 pages, illustrations, 15.5 × 23.5 cms. New York, John Wiley & Sons, Inc. London, Chapman & Hall, Ltd. 1934. Price $5.00.

This new text, while meant primarily for students, is the type best illustrated as being profitable for perusal by practicing engineers to bring them up to date on new original material and a different method of presenting old material. It fills a need therefore to both students and graduates.

In "Introduction" the problem of design is discussed which involves the functional design and structural design, it being assumed that the user of the book has had the usual undergraduate courses in the theory of simple structures and in the mechanics of materials. Following this is a chapter describing ordinary building and bridge frames, illustrated with numerous sketches and photographs of actual structures.

The three major chapters of the book are devoted to the three primary structural forms and their connections. They are (1) the design of beams and girders, (2) tension and compression members, and (3) connections. This portion of the text contains eighteen of the twenty-four sets of illustrative design calculations.

The rest of the text proper treats on design of structures as a whole—buildings, railway and high bridges—and structural welding. Three appendices give design specifications for structural steel for bridges and buildings.

Throughout the book the discussion proceeds from the simple to the more complex.

R. H. OPPERMANN.

EXPERIMENTAL PHYSICS, A SELECTION OF EXPERIMENTS, by G. F. C. Searle, Sc.D., F.R.S. 363 pages, illustrations, tables, 14.5 × 22.5 cms. Cambridge, University Press, 1934. Price $4.50.

This book gives accounts of experiments devised for instruction of students at the Cavendish Laboratory. Its scope includes subjects not covered by previous works of the author, in fact, in the Preface the author states that this work is referred to by Prof. E. V. Appleton as "The Odds and Ends Book." The experiments described deal with such subjects as the determination of frequency of alternating current using the stroboscope, Kater's pendulum, and the recording gyroscope. These are taken from Chapter I and II. Subsequent chapters treat on Elasticity, Surface Tension, Viscosity, Heat and Sound.

Preceding the experiments on surface tension, conduction of heat and on sound there are parts entitled mathematical discussions, in which the student is prepared for the experiment with a good treatment on the nature of the subject. This makes for a more thorough understanding.

One of the exceptional features of the book is the very clear introductions to each subject. In a rather brief space there is defined the subjects and the reasons for the experiment in such a way as to encourage the student to proceed further. At the end of the book, Note I, there is described Aubery's method for combination of observations, and, Note II treats on the exact equation for spherical waves.

R. H. OPPERMANN.

TORSIONAL VIBRATION, ELEMENTARY THEORY AND DESIGN CALCULATIONS, by W. A. Tuplin, M.Sc., 320 pages, illustrations, tables, 14.5 × 22.5 cms. New York, John Wiley & Sons, Inc., 1934. Price $5.50.

As the title implies, this book is a text on a highly specialized subject, applicable to a large and diversified field. Perhaps the best illustration of a torsionally vibrating system is that of a multicylinder engine which is the prime mover most likely to give rise to serious difficulties. Safe working conditions, however, must be thoroughly investigated with any machine which gives rise to a periodic torque.

The simplest case of a torsionally vibrating system is the single mass system in which a shaft is rigidly held at one end and at the other end carries a rotor. While such a case is not commonly encountered in practice, a mathematical consideration is given in order that the chief characteristics of torsional vibration, free and forced, damped and undamped, might be explained in the simplest manner. It is by such detailed treatment that the user of the book gains a comprehensive knowledge of the subject.

Rigorous mathematical analysis of torsional vibrating systems is replaced by an equivalent system, by the use of certain semi-empirical rules. The designer however is still faced with prohibitive numerical work and it is the author's purpose to explain how the designer's calculations may best be made. In determining the natural frequency of a three mass system it is necessary to solve a quadratic equation. In dealing with more complicated vibrating systems, frequency equations of higher degree arise, and a general method of obtaining the roots of numerical equations of any degree must be considered. A description of "Horner's Method" is given which is a special scheme for enabling the trial of any estimated root to be effected with minimum labor.

Aside from what has already been touched on the book contains chapters on Natural Frequencies and Special Cases of Multi-Mass Systems, Harmonic Analysis, Critical Speeds for Torsional Vibration and Forced Vibrations at Resonance. Up to this point an understanding of the basic theory requires no acquaintance with the calculus. Following, there is taken up in detail the principle of operation of vibration dampers, the effect of fluctuating torque in geared systems and torsional impact. An explanation of the Geiger torsiograph is given, the fundamental principle of which is applicable broadly to other torsional recorders.

The book is undoubtedly of great value to those whose interests lie directly in line with the subject and it is a very good reference work useful to all engineers whose work has to do with rotating shafts.

R. H. OPPERMANN.

PUBLICATIONS RECEIVED.

Men, Mirrors, and Stars, by G. Edward Pendray, 339 pages, illustrations, 14 × 21 cms. New York and London, Funk & Wagnalls Company, 1935. Price $3.00.

The Nitrogen System of Compounds, by Edward Curtis Franklin, 339 pages, illustrations, 15.5 × 23.5 cms. New York, Reinhold Publishing Company, 1935. Price $7.50.

X-Rays in Theory and Experiment, by Arthur H. Compton and Samuel K. Allison, 828 pages, illustrations, tables, 15.5 × 23.5 cms. New York, D. Van Nostrand Co., Inc. Price $7.50.

Fundamentals of Dairy Science, by associates of Lore A. Rogers, second edition, 616 pages, tables, 15 × 23.5 cms. New York, Reinhold Publishing Corp., 1935. Price $6.00.

An Introduction to Structural Theory and Design Theory, by Hale Sutherland and Harry Lake Bowman, second edition. 318 pages, illustrations, tables,

15 × 23 cms. New York, John Wiley & Sons, Inc.; London, Chapman and Hall, Ltd., 1935. Price $3.50.

Biology for Everyman, by J. Arthur Thomson, edited by E. J. Holmyard, two volumes, illustrations, 13 × 20 cms. New York, E. P. Dutton & Co. Price $5.00.

Canada, Dominion Bureau of Statistics, Fisheries Statistics of Canada, 1933. 281 pages, illustrations, tables, 16.5 × 25 cms. Ottawa, King's Printer, 1934.

Die im Innern erdähnliche Sonne, Eine neue Anschauung von Aether, Schwerkraft und Sonne, von Dr. phil. Hermann Fricke, 73 pages, 14 × 20 cms. Weimar, R. Borkmann, 1934.

Cugle's Two-Minute Azimuths, by Charles H. Cugle. 613 pages, 21.5 × 28.5 cms. New York, E. P. Dutton & Co., Inc. Price $5.00.

La Masse et l'Énergie le Noeud Gordien de la Doctrine Einsteinienne, par Marcelin Dubroca, 196 pages, 16.5 × 25.5 cms. Paris, Gauthier-Villars et Cie, 1934. Price 18 francs.

Ontario Department of Mines, Forty-third Annual Report. 153 pages, tables, 16.5 × 25 cms. Toronto, King's Printer, 1935.

United States Bureau of Mines, Monograph 5. Gas-, Coke-, and Byproduct-Making Properties of American Coals and Their Determination, by A. C. Fieldner and J. D. Davis, 164 pages, diagrams, tables, 15.5 × 23 cms. Washington, Government Printing Office, 1934.

National Advisory Committee for Aeronautics, Twentieth Annual Report, 1934. 42 pages, 23.5 × 29 cms. Washington, Government Printing Office, 1934. Price fifteen cents.

Bell Telephone Laboratories, Monographs: B-820, Applying Sound Measuring Instruments to the Study of Phonetic Problems, by John C. Steinberg, 9 pages, illustrations. B-822, Relation of Hardness of Non-ferrous Metals to Strength and Workability, by J. R. Townsend, 16 pages, tables. B-825, The Microdensitometer as a Laboratory Measuring Tool, by W. R. Goehner, 10 pages, illustrations. B-826, An Acoustic Spectrometer, by C. N. Hickman, 4 pages, illustrations. 4 pamphlets, 15 × 23 cms. New York, Bell Laboratories, 1935.

National Bureau of Standards, Miscellaneous Publication M-146, Psychrometric Charts for High and Low Pressures, by Donald B. Brooks, 8 pages, charts, 20.5 × 27 cms. Washington, Government Printing Office.

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CURRENT TOPICS.

Traces From Ions.—(*Chemical Industries*, Dec. 1934.) The Chemical Industry Medal for 1934 was awarded to Dr. Floyd J. Metzger of the Air Reduction Company. In his speech of acceptance he tells an extremely interesting story about the separation of the rare gases from air. A better understanding of the problem may be obtained from a consideration of the atmosphere's composition. Nitrogen and oxygen are present as 78.03 per cent. and 20.99 per cent. of the volume respectively. Argon, next to the lightest of the rare gases, comprises almost one per cent., 0.94 to be exact. From there, the task begins: Neon is present as only 1 part in 65,000; Helium, 1 part in 200,000; Krypton 1 part in 1,000,000; and Xenon, 1 in 11,000,000.

Surely, the last two gases named exist in the atmosphere only as traces. Even with 100 per cent. recovery, it would be necessary to process 173 tons of air for the separation of one pound of krypton and 1,208 tons for one pound of xenon. Since the boiling-points of these two elements are above that of oxygen, they tend to accumulate along with the latter in the warm end of the liquefaction system. The separation of krypton and xenon, each in pure form, was quite another matter. Such was accomplished by selective absorption in activated carbon at low temperatures. At one time it was thought impossible to prepare krypton with less than $1\frac{1}{2}$ per cent. xenon. However, it was eventually shown that previous data as to the density of krypton was in error and that the gas, from the beginning, had been 100 per cent. pure.

Unfortunately, the spectroscope could not be relied upon to detect even considerable amounts of impurities in certain combinations of gases. For example, while one part of krypton in one million oxygen is readily detectable by visually observing its electric discharge through a spectroscope, one per cent. oxygen in krypton cannot be so detected. Again one part of krypton in 3,000,000 helium can be spectroscopically spotted whereas about one part helium in two parts argon is the limit for those two gases.

Argon, to date, has found its greatest use in connection with incandescent filament lamps. By substituting argon for nitrogen in these lamps considerable greater efficiencies are obtained; tens of thousands of cubic feet per month are consumed for this purpose. Argon also is used in the manufacture of rectifying tubes and admixed with other gases in many of the well known luminous tubes.

Neon is quite characteristic in its high electrical conductivity and light-emissive power when an electrical current is discharged there through. For this reason it finds its greatest application in lights of the gas-discharge type now so familiar in display signs. These tubes usually are operated with high tension current (5,000 to 15,000 volts and 15 to 50 milliamps.) and in lengths up to 50 or 60 feet.

Helium also is used in the lighting field particularly for the production of yellow and "white" lights. There is a good possibility that krypton and xenon will eventually replace argon in lamp bulbs. G. Claude has found that a 25 watt filament lamp containing krypton and xenon will operate at an efficiency one-third greater than the same lamp containing argon. C.

The World's Largest Diesel. (*Power*, Vol. 79, no. 2.) A rather unusual combination of a steam and diesel power plant is that of the Oersted Station in Copenhagen, Denmark, described by H. WALTER PYE. The world's largest diesel is an 8-cylinder double-acting, two-stroke-cycle motor with 33 in. bore, 59 in. stroke operating at 115 r.p.m. Normal output is 12,500 Kw.; at this load maximum efficiency is obtained and guaranteed fuel consumption is 0.53 lb. per net Kw.h. Maximum continuous rating is 15,000 Kw. with net fuel consumption of 0.44 per net Kw.h. The diesel-generator was installed for standby and peak load purposes. It was brought up to full speed and synchronized in 1 minute and 40 seconds. Of course no fuel is required while standing by. R. H. O.

Rubberizing the Car.—(*Science Service.*) MR. CURT SAURER, speaking before the Society of Automotive Engineers, pointed out the large part played by rubber in construction of the modern automobile and made a number of interesting predictions.

In the future, Mr. Saurer reports, it may be possible to remove the spring and ride on rubber. There also may be a rubber mounting between the motor and the running gears of the car as well as between the gear box and the wheels. Cars of the future may have a rubber covering on the under side of the mud guards to protect the metal from the impact of stones and to reduce the noise of such impacts. Scientists are at work on the problem of rubber seat cushions. They may be in the form of the familiar sponge rubber or perhaps as rubber threads. Some day we may all be riding on a pile of rubber bands. C.

Multi-Unit Heating Plant.—(*Pr. Plant Engineering*, 34, No. 2.) An unusual installation for the production of heat in large quantities is that of Mount Holyoke College. One hundred and twenty General Electric LA-5 domestic oil furnaces are arranged to operate automatically in a single battery. The plant, almost invisible, is built in a space formerly used for storage of fuel. The steam generating battery consists of 24 groups of five furnaces, each group being arranged to operate as single units, although any of the furnaces comprising a group may be withdrawn from service for inspection or adjustment. An automatic regulator actuated by the pressure in the main steam drum brings successive groups into service to the number required to maintain steam pressure between 8 and 11 lb. per sq. in. Oil is stored underground and is pumped to a distributing header which is at atmospheric pressure. Each furnace takes its fuel from it separately. Steam from the drum is distributed to 24 buildings.

R. H. O.

Measuring Corrosion of Metals.—(*Ind. and Eng. Chemistry*, Analytical Edition, Vol. 7, no. 1.) Every so often there appears information that reminds us of the ingenuity of the laboratory technician. A very interesting exhibition of this is recorded by W. R. VAN WIJK. In studying the action of corrosive agents on metals, accelerated corrosion is often applied to save time. Such tests however rarely give comparable results. A method has been devised whereby even the slightest corrosion can be measured quantitatively with great accuracy in a reasonable time. Differences of five atomic diameters may be measured by subliming extremely thin layers of metal (about 8×10^{-6} cm. thick) on glass plaques in high vacuum and measuring their thickness before and after subjecting them to corrosive action by determining the coefficient of the light transmissibility of the metal coated plaques. Sublimination of the metal was accomplished by placing a piece of it in a fine tungsten coil and lowering it in an evaporation bell until it was opposite a number of clean glass plates. By means of pumps, a vacuum of the order of 10^{-4} mm of mercury was obtained in the bell. Electric current was passed through the tungsten coil sufficient to give a temperature near the melting point of the metal causing the metal to disappear and form a coating on the glass. The sublimation of iron and copper presented no difficulties.

The transmissibility of the metal layers was measured optically by passing the light of an incandescent lamp through filters and lenses. It can be calculated by means of the electromagnetic theory of light. For a thick layer the weakening of the light due

to the presence of the layer can be divided into two factors, one representing the weakening by absorption and the other the weakening by reflection against the metallic mirror. With thin layers this division is no longer possible. This is one reason why it is desirable to use metal layers of certain thicknesses.

R. H. O.

$C_{10}H_{18}$.—(*Chemistry and Industry*, **54**, no. 3.) Decahydronaphthalene is now manufactured by a new process by the Imperial Chemical Industries Ltd. made possible by an important extension of hydrogenation technique at their Billingham (England) factory. It is a water-white liquid with a pleasant odor and is used as a solvent and thinner in the paint and varnish industry. The new process allows it to be sold considerably cheaper than turpentine in England. Such intrinsic properties as a very high flash point, leading to a reduction of the fire risks normally run with the more usual thinner, an absence of toxicity shown by prolonged tests and practical use, and a solvent power of exceptional range where paint and varnish materials are concerned are claimed by the manufacturers.

R. H. O.

Incompatibility of Sea-Shells and Oak Cabinets.—(*Chemistry and Industry*, **53**, 1077.) What in unenlightened times may have been looked upon as a wholly mysterious and baleful effect of oak wood upon various objects is now described as merely another natural phenomenon by J. P. NICHALLS, of the British Government Laboratory, the author's own work was a study of the deterioration of shells when stored in oak cabinets. As a background for his investigation he has recorded a case where lead roofing laid on oak became incrusted in 8 years while that laid on deal remained sound for 85 years. The corrosion amounted to 7 lbs. of lead per square yard. There is also a case reported where lead medallions contained in oak museum cases became badly corroded even though the lead objects were resting on cardboard slips.

This corrosion is explained by the fact that oak wood constantly gives off traces of acetic acid vapor. Therefore it was not surprising to find that the incrustation on a number of shells that had been stored in drawers of oak was calcium acetate, as a result of the reaction between acetic acid vapors and the lime composing the shell. However, this did not explain why, when stored under identical conditions, some shells were heavily, some lightly and some not at all attacked. The clue to these differences was found in the traces of salt associated with the incrustation. Washings from

shells which showed no sign of attack contained no chlorides whereas washings from incrusted shells gave reactions for chlorides varying with, and roughly proportional to, the area attacked.

The mechanism of deterioration therefore appears to be as follows: Marine shells retain sea-water which, on evaporation, leaves a small residue of salts. The residue, being hygroscopic, is in a condition to absorb the acetic acid vapors, which would react with the calcium carbonate of the shell forming the incrustation. Microscopical examination of scrapings from the shells showed no mold growth and bacteriological cultures showed no bacteria associated with the deposit.

C.

3′-Me-Cy-Pe-Ph.—(*Chemistry and Industry*, **53**, 1081.) At a general meeting of the Montreal Section of the Society of Chemical Industry, Dr. D. L. THOMSON spoke on 3′-Methylcyclopentenophenanthrene, a Chemical Key to Biological Processes. As an introduction Dr. Thomson pointed out that similar structures such as wings may originate in different creatures from different anatomical sources. On the other hand, one common material may develop into different structures, for instance into hair, wool, fur, scales, or quills. Also one chemical compound, with slight modifications, may be found to exert wide and diverse influences on the living organism. Thus 3′-methylcyclopentenophenanthrene has been shown to constitute the skeleton of cholesterol, that alcohol so widespread in the animal kingdom. It also constitutes the skeleton of ergosterol, the progenitor of Vitamin-D. Cholic acid, one of the bile acids, which aids in the digestion of fats, is also a derivative of this chemical compound. Other derivatives include digitalis, a powerful heart stimulant and strophanthin, familiar as an arrow poison.

The male and female hormone are other derivatives from the basic 3′-methylcyclopentenophenanthrene nucleus. It is also significant that the active ingredient in coal tar pitch found responsible for causing cancer in workers exposed to this material is a compound very similar in structure to the one here discussed.

C.

Metal Shrinking by Dry Ice and Alcohol.—(*Steel*, Vol. 96, No. 2.) Shrink-fits usually associate themselves with heat. A description of the successful use of refrigerants is therefore of much interest. A. W. Brown and E. V. David report on the method used in shrinking four bearing hubs in girders to be used on a bascule bridge over the Shrewsbury River in New Jersey. A cylindrical container of

steel of sufficient diameter and height was constructed so that each of the four bearing hubs could be placed in it for cooling. It was insulated to keep out heat from the surroundings and a circular wooden lid provided to cover the hub while cooling and to minimize cold losses. As each cast steel hub weighed 6,390 pounds, means had to be provided for lifting the hubs in and out of the container. A bronze bushing was fitted in the hub which weighed 2,050 pounds, making a total of 8,440 pounds. After the bushing and hub were lowered into the container and resting on suitable wooden supports, industrial alcohol was poured in until the top of the bronze bushing was covered. Then dry ice was broken up into small pieces, by hammering it in bags, and dropped into the alcohol. The alcohol "boiled" quite noticeably. The mixture was stirred occasionally. After 2½ hours the bearing hub was removed and quickly calipered. The diameter was found to have shrunk 0.030 inch or 0.012 inch more than required. The bearing hub then was moved over the hole for it in the bascule bridge girder and lowered into it quite easily. The temperature of the alcohol in the cooling chamber at the time the bearing was taken out was found to be −54.4 deg. Fahr. The remaining three hubs were shrunk in their respective bascule bridge girders a short time afterward.

Alcohol was used as a heat transfer medium because it allows a speedy transfer of heat and because it would not freeze, the temperature of dry ice being −109.35 deg. Fahr. and the freezing temperature of alcohol being −175 deg. Fahr. By noting the amount of "boiling" a good idea was possible of when complete cooling of the part had occurred. Also, when the part was removed from the liquid it was covered with a thin film of alcohol which prevented formation of frost on it making it difficult to insert in the hole.

R. H. O.

Going Nature One Better.—(*Brodilnaya Prom.*, 10, No. 4, 20–23 (1933).) From time to time we hear of someone who has irreparably altered the nature of living cells by exposing them to X-rays or a similar type of radiation. Now G. NADSON and E. POKHLINA report that when a certain strain of yeast was subjected to the influence of the radioactive gas, Radon, new forms were obtained having distinct morphological and physiological properties which are transmitted from generation to generation. Two derived races, A and B, exhibited peculiarly striking features. Yeast cells of the type A are usually spherical, while colonies of the type B consist of long cells, having one or several vacuoles. In a fermenting mash, race B is characterized by rapid settling, and consequently by rapid clarification, which makes it possible to eliminate filtration. The

yeast yield of B exceeds that of the original by 32 per cent. The fermentive power, measured by the amount of carbon dioxide evolved, of A, B and the original is, respectively, 112, 106 and 100 per cent.

C.

The Indian Sign.—(U. S. D. A. Clip Sheet No. 864.) DR. YOSMITE NABONA, self-adopted member of the Colorado Navajos, was recently fined for violation of the Federal Food and Drugs Act. Dr. Nabona, who posed as an American Indian, was in reality a German by birth and it was found that he sent money at fairly regular intervals to a person, Frieda Anacker, in Germany. Although he listed in his advertising booklets a hundred diseases including Bright's disease, pneumonia, syphilis, arthritis, epilepsy, paralysis and tumors, "Doctor" Nabona's sole claim to diagnostic and professional ability rested upon a "diploma" purporting to come from the University of Berlin, which, when translated, proved to be a midwife's certificate.

C.

New and Better Tuberculin.—The U. S. Department of Agriculture reports that a new tuberculin, free from foreign protein, has been in use since last April in the testing of cattle for tuberculosis. The new tuberculin is made from a pure chemical which takes the place of meat broth. The product is even more reliable in revealing the presence of tuberculosis than the broth tuberculin which for more than 40 years has been produced by practically the same method as was devised by Robert Koch, discoverer of the product.

The new tuberculin is prepared from cultures on a synthetic medium composed of various pure chemicals in the precise proportion required for maximum growth by the bacteria that cause tuberculosis. The most important single ingredient in this medium is asparagin—a pure crystalline amino acid—which furnishes the nitrogen the bacteria require without introducing any protein whatever. The synthetic medium will grow about 4 times as many bacteria as an equal quantity of broth culture.

Asparagin, until 1930 a rare and expensive biochemical product, can now be obtained commercially, by chemical methods, from seedlings of the white lupine and of the soybean.

C.

Preventing Sap-Stains in Lumber.—Discoloration of unseasoned logs and lumber by sap-staining fungi—the blue stainers particularly—may now be avoided by simple, inexpensive treat-

ments developed by the U. S. Department of Agriculture in cooperation with southern lumbermen. More than 200 chemicals or combinations of chemicals were tested by the Division of Forest Pathology. Two of these treatments—one, a water solution of organic mercury compounds, and the other a mixture of chlorinated phenols at relatively low concentrations—will control sap-stains in either pine or hardwoods. A third treatment—borax in saturated solution—is effective on hardwoods only.

C.

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